MEDICAL ASPECTS OF ATOMIC WARFARE

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I

NUCLEAR PHYSICS FOR THE MEDICAL OFFICER

PART ONE—X-RAYS AND RADIOACTIVITY

1. Introduction

Since many medical officers have little background in the subject of nuclear physics, a word of encouragement is in order. It is the purpose of this pamphlet to give such officers some appreciation of the physical basis for understanding radioactivity and nuclear fission. What is presented is a non-mathematical and an understandable explanation of these topics.

2. The Electrical Nature of Matter

The concept of the atom as a structure which is mostly " space ", is one which can be appreciated only by realizing the magnitude of atomic and nuclear dimensions. Merely to state that the radius of a hydrogen atom is 10^{-8} cms and the radius of its nucleus is 10^{-13} cms might not be too revealing as many are unfamiliar with the notation used here, *i.e.*, 10^{-8} cms. This is scientific shorthand for 0·00000001 cms or one-hundred millionth of a centimeter. However, the radius of an atom is generally 10^{-5} or 100,000 times larger than the radius of its nucleus.

Since the electrons are the only particles which are found in the atom outside the nucleus and since these electrons are negligibly small in size, it should be clear that most of the atom is a void. Why then should the atom possess such apparent shape or rigidity which we know it must. The reason lies in the electrical nature of the nucleus of the atom as well as of the electrons which speed about the nucleus in never ending orbital paths. In every normal atom the nucleus carries a positive charge which is exactly the same as the total negative charge of all the electrons in the atom. It is known that each electron carries a discrete electric charge of $-e$ ($4{\cdot}8 \times 10^{-10}$ e.s.u.) units. We also know that each positively charged particle (proton) in the nucleus carries a charge of $+e$ units. For any neutral (uncharged) atom, the number of protons within the nucleus is exactly equal to the number of orbital electrons. It is important to point out that there are no electrons inside the nucleus.

Between the protons inside the nucleus and the electrons outside there exists an electrostatic force which pulls the particles toward each other. However, the electrons are moving with high velocity around the nucleus and the centrifugal force due to the whirling motion is just balanced by the electrostatic force. Thus the electrons perpetually whirl around the central nucleus in orbital paths.

3. The Outer Part of the Atom

Starting with the simplest atom (hydrogen with atomic number 1) the number of orbital electrons is one. For heavier elements, more and more electrons are found in the orbits. Helium with $Z=2$ (Z is the atomic number) has two electrons; iron with $Z=26$ has 26 orbital electrons and uranium has 92 such electrons. These electrons arrange themselves in certain very definite ways about the nucleus and obey rigorous atomic rules. Thus they build themselves up about the atomic core in systematic shells

which are peculiar in that each shell can contain just so many electrons. When one shell is filled, the electrons start another shell which is farther from the nucleus.

Those electrons which are in the outermost shell are called the valence electrons. These determine the chemical properties of the atom. Since these outer electrons are farthest from the nucleus it is reasonable to suppose that these electrons will not be bound as tightly to the atom. The outer electrons are in a sense shielded from the nuclear charge by the inner electron shells so they cannot " see " the nucleus. On the other hand, those electrons in the innermost shell (the innermost shell is called the K shell) are close to the nucleus and are thus most tightly bound to it.

4. Ionization of an Atom

If by some means we could pull one of the outermost electrons away from an atom, the resulting atom would no longer be electrically neutral but would have a net charge of $+1$. The process of removing an electron from an outer shell is called *ionization* and the resulting atom is called an ion. An atom can be ionized by shooting high speed electrons at it. These minute projectiles may collide with some of the outer electrons and knock them out of their orbits away from the atom.

From a medical viewpoint the ionization process is of tremendous importance since it is the start of the process by which tissue suffers radiation damage.

By bombarding an atom with very high energy electrons it may happen that an electron in a K shell will be knocked out of the vacancy in it and one of the outer electrons jumps down into the K shell to fill it up. In jumping down (an electronic transition) energy is liberated from the atom in the form of an X-ray.

5. X-ray Emitted from Atoms

The emission of an X-ray from an atom always occurs when an electron from an outer shell jumps down to fill a vacancy in a K shell. Because the electrons in different atoms (of different elements) are bound to their respective nuclei with different energy, the energy of the X-ray given off will depend upon the element which is producing them. All medical officers undoubtedly have had experience with X-ray tubes which have different elements for targets and know that the $K\alpha$ radiation from a tungsten target is much " harder " than that from a copper target. We are now at a point in the discussion where we must introduce a quantative measure for X-radiation. We have mentioned " hard " radiaton but for any real discussion we must specify the nature of the radiation more exactly. To do this we can either refer to the energy of the X-ray or to its wave length. Energy is usually measured in terms of electron volts (at least for X-rays). An electron volt is that energy which is acquired by an electron as being accelerated across a potential of 1 volt. In X-ray tubes, the electrons emitted by the filament are accelerated by perhaps 100 kilovolts (100,000) and we therefore say that these electrons acquire 100,000 ev (electron volts) of energy.

X-rays sometimes behave as though they were " particles " and sometimes they act like " waves ". In the literature X-rays are often called photons or quanta. It is a fundamental rule in physics that every particle has associated with it certain wave properties and can be described as having a definite wave length. Wave length in the X-ray region is usually measured in terms of 10^{-8} centimeters and since this is a very small quantity it is called by a special name of its own—the Ångstrom unit. It is abbreviated as Å.

If an X-ray photon has very high energy, say 1 million electron volts (1 Mev) it is said to have a short wave length or to be a very hard X-ray. On the other hand, if it is a photon of lower energy, say ·03 Mev it is a long wave length X-ray and is said to be "soft". The wave length (X) is analytically given by the expression $\frac{12,200}{E}$ in A. if E is the energy in ev.

6. Construction of the Inner Part of the Atom

The central core or nucleus of the atom while it is a dense sphere taking negligible space within the atom is composed of smaller units or particles. One of these particles—the proton—has already been mentioned but little has been said about it. In addition to protons, every atomic nucleus except ordinary Hydrogen contains another type of particle—the neutron. The neutron differs from the proton in that it does not have an electrical charge. It is electrically neutral. Both the neutrons and protons are about the same in weight and each is about 2,000 times heavier than an electron.

Therefore the bulk of all matter is found within the nucleus and perhaps an analogy will serve to illustrate this. If you as an individual were suddenly to be disintegrated so that the nuclei in the atoms of your body were free to come together all your weight could be concentrated in a speck on the end of a pin. Because the nucleus has its components so closely packed together we say that it has high density. Along with this close packing of neutrons and protons, there must be some force which acts between these particles. By the way, particles inside the nucleus are called *nucleons*. This force which acts between nucleons and holds the nucleus together is a queer type of force which is called "nuclear force". It is this force which is responsible for the enormous energy which is locked up within the nucleus. The energy is usually called the "binding energy" of the nucleus since it binds the nucleons together in a compact system.

7. Gamma Particles Emitted from the Nucleus

When the nucleus of an atom suffers a collision with a high energy particle, it may become "excited" by virtue of having absorbed energy from the collision. One way in which the nucleus can get rid of this energy is by emitting a photon. This photon is called a gamma particle and differs from an X-ray only in that it is generally a higher energy photon. Otherwise a gamma particle emitted by a nucleus is identical with an X-ray. In fact, recent advances in X-ray tubes have resulted in the production of very high energy X-rays. Such X-rays may be called gamma rays or vice versa.

Once a nucleus emits a gamma particle, it may return to its former unexcited or normal state. Experimentally, many substances may be made to emit such gamma particles by irradiating them with a cyclotron beam or by placing them within a neutron reactor (a pile).

8. Other Particles Emitted from Nuclei

About fifty years ago it was observed that certain elements give off penetrating radiations. Elements such as uranium and radium give off a variety of radiations and are called radioactive elements. The phenomenon is known as *radioactivity*.

Besides emitting gamma particles, these elements were observed to give off two other different types of particles.

A—Alpha Particles (α-particles).

These are just helium nuclei moving at high velocity. They thus are particles composed of 2 neutrons and 2 protons. Compared to an electron, such a nucleus is massive and might be expected to be easily absorbed in matter. This is really the case for most alpha particles are completely stopped by a few sheets of thin paper. We shall see later that this very short range of action for an alpha particle does not prevent it from being effective in damaging cell tissue.

B—Beta Particles (β-particles).

Beta particles are simply ordinary electrons which are emitted from nuclei. They move with high velocity (almost the speed of light) and are not as easily stopped in matter as are α particles. β particles of a few million volts energy will, however, be completely absorbed by several sheets of aluminium. A beta particle is created in the process of emission just as X-rays are created. Before emission an atom does not contain an X-ray and in like manner neither does a nucleus contain any electrons.

9. Radioactive Transformations

In the act of emitting an alpha particle, a radium atom must undergo a change in its nuclear structure for the two neutrons and two protons which make up an alpha particle are subtracted from it. Technically, we say that the radium atom undergoes a *radioactive transformation*. To facilitate our consideration of these nuclear change-overs, we will introduce some nuclear nomenclature. For example, we shall describe the radium nucleus by the symbol ${}_{88}Ra^{226}$. Here the superscript is called the atomic weight and is numerically equal to the total number of neutrons and protons in the nucleus. The subscript 88 is the atomic number or charge and is numerically equal to the total number of protons in the nucleus. Thus we have a neat symbolic way of writing down basic information about an atom. Elements such as tin (atomic number 50) have a variety of different weights since some tin nuclei have more *neutrons* than others. These atoms of tin which have different numbers of neutrons are known as *isotopes* of tin. Some elements have only 1 isotope whereas others may have as many as 10 isotopes, each of which is present in different proportions.

When ${}_{88}Ra^{226}$ emits an alpha particle (symbolized by ${}_{2}He^{4}$ since the particle has atomic number 2 and 4 nucleons in its nucleus) it transforms itself into a new element known as radon. This reaction may be written as

$${}_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + {}_{2}He^{4}.$$

Radium goes to radon plus an alpha particle.

Analogous to chemical reaction equations, we have " balanced " the equation and obtained a resultant atom of radon which has $Z=86$ and a total number of nucleons equal to 222. Instead of referring to this process as a radioactive transformation, we can also call it a radioactive decay or disintegration. Another point of terminology is to call the decaying isotope the " parent " and the disintegration product the " daughter ". For radium, the parent is the ${}_{88}Ra^{226}$ isotope and the daughter is the heaviest particle —the radon isotope ${}_{86}Rn^{222}$.

10. Radioactive Series

Radium is only one of the many radioactive isotopes which occur in nature. It is perhaps the one which is most familiar. Radium is itself the daughter of a thorium isotope which in turn is a daughter of a uranium isotope. There are thus a *chain* or a *series* of isotopes which are respectively parent and daughter to each other. The radon which is formed from radium is also radioactive and decays to form polonium and this forms an isotope of lead. Up to this point we can describe this series of events by the relation:

$$_{92}U^{234} \xrightarrow{\alpha} {}_{90}Th^{230} \xrightarrow{\alpha} {}_{88}Ra^{226} \xrightarrow{\alpha} {}_{86}Rn^{222} \xrightarrow{\alpha} {}_{84}Po^{218} \xrightarrow{\alpha} {}_{82}Pb^{214}$$

Uranium to Thorium to Radium to Radon to Polonium to Lead.

The α over the arrow indicates that an alpha particle is emitted in the decay process. Now lead is commonly thought of as a very stable element. By that we mean that it does not undergo radioactive decay. However, the isotope of lead which is formed in the radioactive series above is not stable. It has 214 nucleons in its nucleus and since it must have 82 protons, there are $214-82$ or 132 neutrons in the nucleus of this atom of lead. Now of the lead atoms found in nature the heaviest isotope is $_{82}Pb^{208}$. Thus the isotope $_{82}Pb^{214}$ is much heavier than the heaviest natural lead isotope for it contains six additional neutrons. Instead of emitting an alpha particle which would make the neutron surplus even worse, the lead isotope $_{82}Pb^{214}$ emits a beta particle and the reaction is as follows:

$$_{82}Pb^{214} \longrightarrow {}_{83}Bi^{214} + {}_{-1}e^{0}$$

Lead goes to Bismuth plus *Electron*.

In this case, lead changes to an element of atomic number higher than it since the emission of an electron is equivalent to *adding* a charge of $+e$ to the lead nucleus. In these nuclear reactions electric charge is always equal on each side of the equation, *i.e.*, charge is conserved. Since the electron has negligible mass the atomic weight of the isotope of bismuth is the same as the parent atom. By succeeding β and α emissions the bismuth atom is finally transformed to a stable isotope of lead—$_{82}Pb^{206}$. This isotope is then the end of this series which is called the uranium-radium series, In addition, two other naturally radioactive series are known—the thorium and the actinium series. The latter both finally decay to stable isotopes of lead.

11. The Rate of Radioactive Decay—the Curie

What about the time scale on which these radioactive transformations take place? Does the radium atom, for example, disintegrate in 1 second or in 1 year? Actually the process is statistical in nature and if we looked at one isolated radium atom, we might see it decay in a minute or we might have to wait a million years for it to disintegrate. If, however, we look at 1 gram of radium atoms, we see that there are so many atoms ($6/226 \times 10^{23} = 3 \times 10^{21}$ atoms) that there is an average value for the time during which 50% of these atoms will decay. This time is called the half life and for radium it is 1,590 years. If we start out with one gram of radium, then in 1590 years we will have only one half gram on hand.

Radium is said to be long-lived but other atoms have extremely short half lives of the order of one millionth of a second. Still others like $_{92}U^{238}$ (the heavy isotope of uranium) are very long-lived, having a half life of 4.5×10^{9} years.

In order to calculate the activity of any sample of a radioactive material we multiply the number of atoms present as follows:

$$\text{Activity} = \frac{(\text{No. of Atoms})\ (\cdot 69)}{\text{Half Life (in seconds)}} = \text{particles emitted per second.}$$

Suppose we calculate the activity of 1 gram of radium. Now 226 gms of radium are equal to 6×10^{23} atoms so 1 gram is $2 \cdot 6 \times 10^{21}$ atoms and since the half life is 1590 years or 5×10^{10} seconds.

$$\text{Activity of 1 gm of Ra} = \frac{(2 \cdot 6 \times 10^{21})}{5 \times 10^{10}} (\cdot 69) = 3 \cdot 7 \times 10^{10} \text{ particles/second.}$$

In practice this activity is called the *Curie* and is an accepted standard unit. The millicurie (mc) unit is one thousand times smaller than the Curie. A millicurie of radium gives off $3 \cdot 7 \times 10^{7}$ particles per second (37 million particles in one second).

The unit is also applied to substances other than radium such as so many millicuries of carbon 14 ($_6C^{14}$) which is frequently used in medical research.

12. The Quantity of Radiation—the Roentgen

In treating a patient with a radium capsule it is necessary to measure the dose which is given. For this purpose we use a unit called the *Roentgen* named after the discoverer of X-rays. The Roentgen is abbreviated *r*, and is defined as that quantity of X-radiation which on passing through 1 cubic centimeter of normal air produces 1 electrostatic unit of ions. While it was originally defined only for X-rays, the definition is equally valid for gamma rays. A smaller unit, the milliroentgen (mr) is often used in practice. The definition is perhaps not too meaningful because of the term—electrostatic unit—which is used. Physically, one should think of the definition as meaning that quantity of X-rays which is measured by a certain number of ions produced in a standard volume of air. It is, of course, a measure of the total energy given up by the X-rays to the atoms of air.

Later on it will be shown that different types of instruments can be used to measure X-radiation. These are ionization chambers, Geiger-Muller counters, and photographic emulsions. One should sharply distinguish between two types of measurements:—

A—Those that measure the *dose* or total *quantity* of radiation.

B—Those which give the *dose-rate* or the intensity of radiation.

Dose is measured in roentgens whereas dose-rate is measured in terms of roentgens/second or roentgens/minute or in other time units. It is one thing to give a patient a dose of 1 r of X-rays and quite another to expose a patient to a dose-rate of 1 r/second. In the latter case, the patient receives a 1 roentgen dose in one second and 60 roentgens dose in 1 minute. In one hour the patient would be dead or would be as good as dead.

II

NUCLEAR PHYSICS FOR THE MEDICAL OFFICER

PART TWO—NUCLEAR FISSION AND THE ATOMIC BOMB

1. Introduction

Being thus prepared with a knowledge of radioactivity and nuclear radiations, it is possible to consider the phenomenon of nuclear fission. As already shown, the nucleus is a compact aggregate of neutrons and protons which are bound together by nuclear forces which act between these particles. If by some process, this compact nucleus can be split, it is known that part of the mass of the original nucleus will be transformed into energy. To appreciate this, it is necessary to discuss the mass-energy relation which was first put forth by Einstein.

2. The Mass-Energy Relation or $E = MC^2$

If in any reaction where there is a decrease in mass of the reaction, Einstein's mass-energy equivalence law requires that this mass must be converted into some form of energy. The resultant energy may be evident in any one of several ways. For example, radiation may be emitted as in gamma ray emission (radiant energy) or particles may be given high velocity (kinetic energy). In any event, the

$$\text{Energy Released} = (\text{Decrease in Mass}) \times (\text{Velocity of Light})^2$$

or

$$E = MC^2$$

Suppose, for example, we split a Uranium 235 atom ($_{92}U^{235}$) into two parts and assume that 1/4 of a mass unit of mass is converted into energy. One mass unit is about the weight of one proton and is equal to 930 million electron volts of energy. One quarter of a mass unit, then amounts to about 230 Mev. Since the original $_{92}U^{235}$ atom weighs 235 mass units, it is equivalent to a total energy of 220,000 Mev. Thus only

$$\frac{230 \text{ Mev}}{220{,}000 \text{ Mev}} = \frac{1}{1{,}000}$$

of the total energy content of the uranium atom is released in this splitting (fission) process. In fission, the greatest part of the 200 Mev of energy is released in imparting high velocity to the split atom parts (fission products).

3. A Physical Picture of the Nucleus

In the foregoing sections, we have indicated something of the nature of the nucleus. Let us now look a little closer at this tiny cluster of nucleons which forms the heart of the atom. We can form a very useful model or picture of the nucleus by thinking of it as analogous to a liquid sphere or water droplet. Inside the confines of this sphere, the neutrons and protons are in a constant state of violent motion, bumping into each other incessantly but always remaining inside the sphere. So strong are the forces between the nucleons that they do not let each other out of " view " and pull each other tightly together. As evidence of this close packing of neutrons and protons inside the nucleus is the fact that the uranium-238 atom (the heaviest naturally occurring isotope) is only slightly larger in size than the nucleus of a light element such as aluminum.

Outside the nucleus, the extremely strong nuclear forces are not felt because these have a very short range of action. However, the protons inside the nucleus make themselves known outside the confines of the nucleus by their electrostatic " field ". This " field " forms a barrier around the nucleus which prevents any charged particles from entering the nucleus. If, however, the particle which seeks to enter it is uncharged, it cannot see the particle and offers no resistance to its entry. For this reason, neutrons of low energy easily slip inside the nucleus whereas protons of very high velocity are barred.

4. A Model of the Fission Process

It is a property of a few very heavy nuclei such as U-235 that when a neutron is added to them, they react very violently by splitting into two almost equal parts. The process is called *nuclear fission* or simply *fission* and the isotopes which exhibit this unusual behaviour are called *fissionable*. The products of the fission reaction, *i.e.*, the two halves of the heavy atom, are known as *fission products*.

We can picture the fission process by bringing into consideration the liquid drop model of the nucleus which we have just discussed. Let us imagine that before the neutron enters the uranium 235 nucleus all the 92 protons and 143 neutrons are in constant motion inside the *spherical* nucleus. Let us assume that because their nucleons are so close together and move about so rapidly that they lose their individual identity and may be thought of as forming a fluid or liquid drop of uniform density. With the intrusion of a neutron into this contented system, the liquid drop has energy added to it and becomes excited. The particles inside the nucleus are set into more violent motion and the drop begins to lose its spherical shape. As it deforms into a non-spherical shape it sets up rapid oscillations which deform it still further into a dumbbell pattern. At this point the original sphere is essentially drawn out into two smaller spheres with a tenuous connecting link which then snaps. Then the two fission products shoot away from each other with high velocity. All this happens in an exceedingly short time interval of less than 10^{-12} seconds.

5. Neutrons Released in Fission

When fission occurs, it is known experimentally that neutrons are released. These neutrons are mostly (over 99 per cent.) emitted within an extremely short time of less than 10^{-10} seconds but a small fraction of one per cent. are *delayed* for as much as one minute after fission has occurred. All neutrons whether *prompt* or delayed are emitted by the fission products. In addition to neutrons, other particles such as gamma rays, beta particles and sometimes alpha particles are emitted in fission.

Let us write down a reaction equation for a fission process:

$$\underset{\text{Uranium 235}}{{}_{92}U^{235}} + \underset{\text{Neutron}}{{}_{0}M^{1}} \longrightarrow \underbrace{{}^{46}Pd^{117} + {}_{46}Pd^{117}}_{\text{2 Palladium Isotopes}} + \underbrace{{}_{0}M^{1} + {}_{0}M^{1}}_{\text{2 Neutrons}}$$

Uranium 235—Neutron 2 Palladium Isotopes 2 Neutrons

This assumes that the nucleus splits into two equal parts. As we shall learn later this is an improbable occurrence in natural fission.

If one looks in a table of stable isotopes one finds that the heaviest natural isotope of palladium is $_{46}Pd^{110}$ while the palladium isotopes shown in the reaction equation are much heavier, having seven more neutrons per atom. From experience, we know that these abnormally heavy isotopes are

not stable and must by some means make up for the abundance of neutrons in their nuclei. This can also be thought of as a deficit of protons in the nucleus. It is thus understandable that neutrons are so quickly emitted by the fission products.

6. Radiations from Fission Products

It would be rare for a pair of fission products to have the same mass and we know that it is much more common for one of the products to be heavier than the other. In general, there are two groups of fission products, one with an average mass of about 95 and the other of about 139. Just why the two fragments are unequal in mass, we do not know.

We do know, however, that the fission products are intensely radioactive, emitting high energy beta and gamma rays. By emitting β-particles, the isotopes which contain too many neutrons (or too few protons) tend to make themselves more normal since we have explained that β-emission is equivalent to changing a nuclear neutron into a proton. Because the fission products are born with such extreme neutron excesses (or proton deficits) it requires four or five separate β-decays to result in stable atoms. Thus each fission product is often associated with a chain of radioactive isotopes and for this reason we speak of *fission chains*. Almost all fission products emit very penetrating gamma rays in addition to beta particles. The half lives for the various fission products vary from micro-seconds to many years.

The result of fissioning a large number of atoms is that we have an aggregate of many different fission products representing almost every element from atomic number 40 to 70.

7. The Chain Reaction

If we wish to talk about the fission of large numbers of uranium atoms, it is necessary to have large numbers of neutrons available. Because the fission process requires only one neutron to initiate it and yet gives off slightly more than two neutrons per fission, it is possible to use fission neutrons to start a " chain " of fission reactions. Each fission adds more neutrons to the reaction so that more and more reactions are possible. Such reactions are called self-sustaining or *chain reactions*.

Since the fission process occurs so quickly, it is conceivable that if we were properly to assemble a certain " critical " mass of fissionable material such as U-235, we could set off a series of fissions which would proceed so quickly that the recoiling fission products and radiations would raise the critical mass to a multi-million degree temperature within a fraction of a second. By definition, such a process would be explosive in nature.

Prior to World War II, no pure U-235 was available. Ordinary uranium metal contains 140 times more U-238 than it does U-235. Now U-238 is not suitable for a chain reaction because when it absorbs a neutron into its nucleus, it merely changes into a heavier element without fissioning. Since the two isotopes of uranium are chemically identical, they had to be separated by exceedingly difficult physical methods. In fact, the methods presented so many technical obstacles, that the Manhattan Project set up huge plants which used nuclear reactors running on natural uranium to generate a new man made fissionable material—plutonium.

8. Plutonium—A Man Made Element

With neutrons released in the fission of the small amount of U-235 present in natural uranium metal, it was possible to sustain a chain reaction and bombard U-238. Under proper conditions a large number of these fission neutrons can be absorbed by the U-238 atoms. This results in an unstable U-239 nucleus which rapidly decays by beta emission as follows:—

$$ {}_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} \longrightarrow {}_{93}Np^{239} + {}_{-1}e^{0} $$

Here Np is the symbol for the new transuranic element neptunium. Neptunium is itself radioactive and soon decays to form an isotope of element 94 which has been named plutonium. Thus

$$ {}_{93}Np^{239} \xrightarrow{2.3d} {}_{94}Pu^{239} + {}_{-1}e^{0} $$

The figure 2·3d over the arrow means that this reaction has a half life of 2·3 days.

Plutonium is a dense silvery metal similar to uranium U-235 in that it is fissionable with slow neutrons (*i.e.*, neutrons which are of low energy). Like U-235 it is also an alpha emitter but since it has a half life of 24,000 years, it is much more active than U-235 which has a half life of 7×10^8 years. The alpha activity of plutonium is sufficiently intense that it constitues a dangerous health hazard of about the same toxicity of radium.

9. The Concept of Critical Size

One of the unique characteristics of an atomic explosive is that it must be assembled into a certain *critical size* before it can explode. The reason for this unusual characteristic is that the chain reaction will not be a self perpetuating one unless there are sufficient neutrons to cause continued fission. Suppose, for example, we wish to run a chain reaction at a rate of 500 fissions per second. Suppose, further, that each fission generates exactly two neutrons. This requires that one out of every two neutrons generated must be used to create more fission, so that we have to have 500 neutrons being used every second to cause fission. This leaves an additional 500 neutrons which we can afford to " lose " from our system either by absorption (not leading to fission) or by loss through escape from the system. When the number of neutrons being produced over and above those needed to keep the fission reaction going at a fixed rate is exactly equal to the number of neutrons lost from the system, we say that the system is *critical* and this mass of material is called the *critical mass*. Masses less than this are called *sub-critical* and larger ones are known as *over-critical* masses.

The trick in detonating an atomic bomb is to make an assembly of fissionable material over-critical as fast as possible and keep it together long enough so that an appreciable fraction of the atoms are fissioned. If one simply stacked up blocks of sub-critical blocks of U-235 until the assembly was over-critical, the chances are that no explosion would result. There would be a neutron " flash " and the heat generated by the fission of some (a small fraction) of the atoms would push the blocks apart and make the assembly non-critical. However, the neutron flash would be dangerous.

10. The Atomic Bomb—How It Works

A logical way to assemble an atomic bomb might be to take two hemispheres of fissionable material each of which is sub-critical and bring them very quickly together to form an over-critical mass. One hemisphere of pure U-235 might be imbedded in a large mass of material (tamper) placed

at the target end of a gun barrel. At the other end of the barrel might be another hemisphere which serves as a projectile. Separated by the length of the gun barrel, each hemisphere would be sub-critical and safe, but by firing the one hemisphere down the barrel, it would attain a high velocity and weld itself together with the target into an over-critical mass. The inertia of the projectile together with the heavy tamper would serve to keep the critical assembly together for an appreciable length of time so that a large amount of the uranium is fissioned. This would insure a high " efficiency " for the reaction.

The Smyth report states that the critical mass is somewhere between 2 and 100 kilograms. For example, let us assume that it is 50 kilograms (110 pounds) and that the bomb efficiency is 2 per cent. This means that one out of every fifty uranium atoms is fissioned. Since 235 grams of U-235 contain 6×10^{23} atoms, this hypothetical explosion would fission a total of $2 \cdot 5 \times 10^{24}$ U-235 atoms. Since each fission would produce two fission products, 5×10^{24} fission products would be formed.

We have seen that 1 Curie is that amount of radiation given off by 1 gram of radium and is $3 \cdot 7 \times 10^{10}$ disintegrations per second. By simply dividing this figure into the number of fissions we see that our hypothetical explosion will liberate 10^{14} Curies of radioactivity! Such is the truly fantastic radioactivity associated with atomic explosives. Using the approximate relation that one ton of radium = 1 million Curies, we see that the above hypothetical explosion is equivalent to about 100 million tons of radium!

11. Atomic Bomb Effects

As medical officers, you will be most interested in and concerned with the new type of damage which is inflicted on personnel by atomic explosions. From your experience in the last war, you are familiar with blast or concussion effects and with flash burn injuries. However, " radiation damage " presents a new and challenging problem to the medical profession. For this reason, the emphasis in these discussions has been placed on radioactivity and on fission products.

While we have discussed various phases of radioactivity, we have not mentioned radioactivity which is induced in materials by the capture of neutrons. We shall briefly discuss the artificial activity induced by neutrons.

If a neutron strikes a nucleus of some element such as sodium it may be absorbed or captured by it. This process is described by the reaction equation:

$${}_{11}Na^{23} + {}_{0}n^{1} \longrightarrow {}_{11}Na^{24}$$

The resulting sodium atom is not normal and emits radiation. For this reason it is called *radio-sodium*. Radio-sodium emits a beta particle of $1 \cdot 4$ Mev and also a gamma ray. Thus, if an atomic bomb explodes close to sea water there will be a neutron induced activity produced since salt in the sea water is present to about 35 grams per litre. Radio-sodium has a half life of $14 \cdot 8$ hours and for this reason the activity will persist for a few days before becoming negligible in intensity. Other elements also can be *activated* by neutron irradiation. This is the means by which Carbon 14, radio-iodine and radio-phosphorus are made. Such radio-elements are now being used in the medical field.

12. Conclusion

In a very real sense, serving medical officers of today are the pioneers in the field of military radiological work. We cannot create overnight, or in a few weeks, or in a year a trained group of medical officers who are cognizant of radiation damage symptoms, and who are skilled in their treatment. Indeed, there is grave doubt that preventive or curative medicine can be practised in this new field. But the stakes are too high for us to despair. We must investigate every possible method of prevention, of diagnosis, and of treatment.

III

EFFECTS OF AN ATOM-BOMB EXPLOSION ON A TYPICAL AMERICAN CITY

1. Introduction

The atom-bomb tests carried out in the South Pacific have tended to make the Western Democracies rather complacent about the destructive power of this weapon. In evaluating the effects of the bombs detonated at Bikini in the summer of 1946, one must bear in mind that it is difficult to compare damage suffered by ships with that sustained by city buildings. The naval vessels riding at anchor in the Bikini lagoon showed comparatively little damage at more than 1,000 yards from the centre of blast whereas at Hiroshima buildings 2 miles from the point of the explosion were severely damaged. A ship is not only an extremely strong structure but it also is able to withstand severe shock by recoiling in the water. In contrast, many urban buildings are extremely weak structurally and being rigidly fixed to a massive foundation, they are easily knocked over by a blast wave.

It is important that one appreciates the real power of an atom bomb, and the purpose of this section is to present a realistic picture of the damage which a typical American city might suffer were an atom bomb to be detonated over it. As a typical city, " City X ", is an excellent choice. Furthermore, it is strategically situated in the industrial heart of the United States so that it would certainly be selected as a target city if that country were ever to be embroiled in another war.

2. The Problem

Just how would an aggressor nation go about atom-bombing " City X "? What type of bomb would it select? At what point would the bomb be detonated? To answer these questions one has to consider many factors.

The type of atomic bomb used would depend upon the technical ability of the aggressor to fabricate and detonate bigger and better bombs. Or perhaps they should be termed bigger and worse bombs. Assuming that the technical difficulties are surmounted and that it is possible to make A-bombs of considerably more than 20,000 tons high-explosive equivalent, then the problem of the selection of the bomb size involves a careful evaluation of the following two factors:

1. How much of the aggressor nation's plutonium (or other fissionable material) reserve could be allocated to the target? This question brings out an interesting fact with which many may not yet be familiar. The world is no longer on the gold standard, it is actually on a plutonium standard. Aggressor nations will measure their wealth in terms of the amount of fissionable material (plutonium) which they stock-pile.

2. What is the military priority of the target? The answer to this question will involve a detailed study of the contribution which the city makes to the nation's war economy.

A glance at the map of " City X " shows that there are at least two areas of prime military importance. One is the " Section A " steel industry and the other is the " Section B " industrial section. Of paramount importance, but not so easily seen on a map, is the wide diversification of feeder industries which abound in the city.

3. A New Bombing Problem

It will be noted that the two critical areas singled out for discussion are separated by about ten miles. In planning an ordinary bombing raid, it would be a simple problem merely to assign so many bombs to each area in the city, but in using atomic bombs, the problem is more complex. Because the A-bomb has such enormous destructive effect, one has to balance desired damage to structures against desired damage to personnel.

It is quite possible that in bombing " City X " it would be decided to use a detonation designed to kill off or injure the maximum number of people in the city and thus cripple the industrial capacity of the entire area. In order to knock out both " Section A " and " Section B " areas with one bomb, the bomb would have to be prohibitively large in size in comparison with the military priority of the targets. Furthermore, the use of more than one atomic bomb would not be feasible since destruction of both areas would not result in sufficient casualties in the crowded residential areas of the city.

4. Point Zero

Without going into a further detailed study of the problem let it be assumed that it is decided to detonate an atomic bomb of 50,000 tons high explosive equivalent at an altitude of 2,500 feet at Point Zero.

The reason for selecting the target centre at Point Zero is that this will ensure that the destructive effect of the bomb will not be wasted over unpopulated or non-critical areas.

If " City X " is situated on the shores of a lake or is so located that its built-up area fans out radially to the North-East, as much as 50 per cent. of the bomb's destructive power could be wasted over the uninhabited South-Western area by exploding the bomb two miles to the South-West of Point Zero.

If one wanted to kill off large numbers of the population and render the city uninhabitable, one might conceivably detonate the bomb in the nearby lake. While no blast damage would be inflicted on the city, it might happen that under proper conditions the prevailing winds would carry lethal quantities of spray-borne radioactive materials over the city, thus raining down upon it lethal quantities of invisible radioactivity.

Why select a bomb of 50,000 H.E. equivalent? This is done to ensure that the destructive range of the explosion will be sufficient to accomplish the objective of killing or maiming the maximum number of people in the area.

Such a bomb would be more than twice as powerful (published value =20,000 tons H.E. equivalent) as the type used on Nagasaki. Without violating any security regulations, it is possible to say a few things about the bomb mechanism. Despite all of its differences from an ordinary explosive,

the atomic bomb has at least one similarity. Under proper conditions, an increase in the amount of charge (fissionable material such as plutonium) can result in a corresponding increase in the over-all explosive power of the bomb.

5. Possible Size Limitations

However, since the trick of setting off atomic explosives is to keep the fissionable parts in a subcritical state until the time desired for detonation, it is obvious that making more-powerful bombs of the Nagasaki type will require considerable development. The reason for this is that, if one assumes that two subcritical masses of plutonium are violently brought together (made critical), then using the same technique more than two such subcritical masses must likewise be brought together if a higher order explosion is desired; this is easier said than done. Furthermore, there is no guarantee that when one successfully detonates such an improved atom bomb, it will have the same efficiency per pound of plutonium as obtained with a smaller bomb. In view of the scarcity of this man made element, it must be carefully rationed in peace and in war.

These two factors, which are obvious to any nuclear physicist, might alone limit the ultimate feasible size for atom bombs but there is another even more convincing reason why plutonium bombs may not be progressively increased in destructive power. This reason, simply stated, is that one 20,000-ton high explosive blast does not do as much direct damage as two 10,000-ton explosions. This rule holds true for all explosives.

6. Altitude of Detonation

How does one decide at what altitude the bomb should be exploded and why are these bombs exploded so high in the air? The exact altitude for detonation depends upon the explosive power of the bomb, the nature of the target, and the type of damage desired over the given area. If one wants to annihilate a small but vitally-important installation, the proper procedure is to explode the bomb as close as possible to the target. But if the damage is to be extended over a much greater flat area, then one simply explodes the bomb high enough in the air so that the blast wave will extend out over the desired area and still produce destructive effects.

At Nagasaki, where the Japanese tell us the bomb exploded 1,800 feet above the ground, there were about ten square miles of land hard hit by the blast. At Alamogordo, N.M., the bomb was only 100 feet above the ground and less than three square miles were damaged to the same degree.

7. The Attack

With the foregoing facts in mind, one can proceed to examine what would happen to the " City X " if it were subjected to an atom bombing of the type just described. Let us assume the attack takes place at noon when the downtown area is most heavily populated.

The city is enjoying a pleasant sunny day with a cooling breeze coming in. The streets are thronged with thousands of shoppers in the downtown and Point Zero areas. Then suddenly and without warning the bomb is detonated high above the city.

A dazzling bluish-white flash blinds those people on nearby streets and sears them at the same time with its million-degree heat. Almost within a thousandth of a second the small ball of fire shoots out to form a sphere of

flame 100 yards in radius. Simultaneously the colour of the ball changes, going over to a varicoloured seething mass which spreads outward and downward at terrifying speed. Above it all, a hugh pinkish white mushroom "atomic cloud" forms and climbs toward the stratosphere.

Directly under the blast, the instantaneous flash of heat sears all pedestrians into unidentifiable charred and grotesque forms. Those shielded from the heat are momentarily conscious of a terrible pressure wave that topples taller buildings and crumbles others into rubble. Within a second a blast wind of near supersonic velocity rushes in and demolishes those buildings untouched by the primary blast wave. The air is thick with dust from pulverized buildings and the crashing of surrounding buildings creates a din which is soon followed by the ominous Niagara-like noise of fires ignited by the flash.

8. Secondary Damage

To feed the multitude of fires, air rushes in from the surrounding area, even overcoming the prevailing breeze, and so on a firewind of gale proportions sweeps the city. This unusual firewind persists for several hours and makes the entire area near the epicentre inaccessible to what fire-fighting equipment is available. Streets made impassable with debris, the failure of the water pressure, disrupted communications all prevent fire fighters from reaching the stricken area.

Within a three-mile radius of the epicentre, the number of dead and injured is staggering to the imagination. Those who were within one mile of the blast centre, while still surviving, are living on borrowed time. When the brilliant flash of light occurred, those living within a mile of the blast centre were exposed to a deadly dose of penetrating radiation. Unseen, unheard and unfelt these deadly rays penetrated the human tissue and left their mark. Perhaps the survivors would linger for a few days, or even a few weeks but they are doomed.

Much of the enormous damage is due not so much to the primary effect of the bomb but to the secondary effects. In this category, one would list fire damage, injuries due to collapse of fire-gutted buildings, deaths from burns, suffocation and lack of medical care. Much of the effectiveness of the A-bomb is due to its instantaneous and widespread action. A modern and efficient fire department, such as "City X" has, can cope capably with a few outbreaks of fire within the city, but when hundreds of fires are simultaneously started miles apart in an impassable area, it is a hopeless task to stem the onrush of the holocaust.

9. Damage at Point Zero

Suppose that the fire burns itself out within the next day and one can then re-enter the area and critically examine the smoldering ruins and evaluate the over-all damage to the area. To make the survey more systematic, let the examination be concerned first with blast damage.

In the map (No. 1), the various zones of damage due to blast are outlined. Since it is difficult to separate the individual effect of the shock wave from that of the blast wind, their combined effect is considered. From the epicentre to a distance of 1 mile there is heavy blast damage. All frame and brick buildings are demolished and only those sturdy, reinforced concrete structures on the periphery of this zone escape complete destruction. Within the zone the interior of all buildings is subject to intensive damage.

Both the downtown and the Point Zero shopping centres on the periphery of this zone sustain extensive damage ranging from total destruction to heavy damage. In some cases the walls of the buildings remain standing but the

roofs and floors are missing. Able Street is a scene of utter desolation. From the City Hall to Baker Street it is impassable. Street cars and automobiles, many with their occupants lying dead inside them, stand out in the rubble strewn streets.

10. Damage 1 Mile from Point Zero

Farther out from the epicentre, within the 1- to 2-mile radius, heavy damage is sustained. Included within this zone is the downtown area of the city. Here some of the larger, well-built structures seem to be intact but closer examination shows that their interiors are extensively damaged and many are gutted by fire. At the lower end of Main Street, the beautiful Memorial Auditorium is in ruins, but many of the buildings along Main Street even closer to the epicentre are almost untouched. Apparently these were shielded by other buildings or merely escaped blast damage by virtue of having been "skipped".

The neon beacon high on top the Charles Building has been ripped asunder and lies in the street below. The main structure remains more or less intact with greatest damage being apparent on the upper part of the building. In spite of the appearance of the exterior of the modern structure, there were many casualties in it and due to the fires which raged throughout the downtown area it was impossible to evacuate all of the occupants of the building.

To the East, the Central Terminal still stands, but severly damaged. Without any shielding from the blast wave, parts of the structure collapsed. The railroad yards are inoperable with twisted rails jutting up from the ground. Apparently many of the railroad ties in the bed were burned by the flash.

11. Damage at a Distance

Between 2 and 3 miles distant from the epicentre moderate blast damage is evidenced among the ruins. The majority of the blast damage is concentrated on frame dwellings and plants of light construction. Brick houses in this zone still stand but show some signs of interior damage.

More than 3 miles from the point of bomb detonation there are still signs of blast damage but for the most part they are minor and are masked by damage from fire.

It is possible for blast effects to be felt at as great a distance as 8 miles from the epicentre, but such damage would be slight and rare.

12. Fire Damage.

When the bomb explodes a vast quantity of radiant energy (light) is liberated in the form of ultraviolet, visible and infra-red radiation. This radiation causes intense surface heating of all objects which it strikes within a 3-mile radius of the epicentre. In some cases, depending on the local conditions, this surface heating is sufficient to ignite the material. Thus, within a circle roughly 6 miles across, there may be hundreds or even thousands of fires started and of these several hundred will persist and spread.

The effect of such intense burning over such a wide area is to cause a mass influx of air from outside the region. This movement continues if it overcomes the prevailing winds and an enormously destructive fire-storm results and whole areas untouched by the blast are burned out.

In " City X " the prevailing South-Westerly wind would overcome the fire-storm after a few hours and tend to sweep the blaze into the B Section of the city. To the North, Forest Lawn and Dog Park would act as natural fire breaks and to the South-West, the South Park section would be shielded by the prevailing winds.

13. Effects of Radioactivity

Before continuing the discussion of the damage inflicted by the A-bombing, it is useful to summarize here certain facts which are known for radioactivity resulting from atomic-bomb-explosions. When Hiroshima and Nagasaki were A-bombed, there was great confusion in the nation about the effects of radioactivity resulting from these explosions. Some of this confusion persists today and the following facts may clarify the situation:

A—Before the bomb is exploded, the material gives off only alpha rays which are easily absorbed in a piece of writing paper. Except for the fact that plutonium is extremely toxic one might treat this material very casually by merely wearing gloves to protect against alpha rays. After the bomb is properly exploded, what plutonium is not " burned " up or fissioned is widely scattered and will persist for many years.

B—When the bomb explodes, an instantaneous burst of neutrons and gamma rays occurs. These penetrating rays flash through the atmosphere and many go right through concrete walls to pass through the bodies of people inside the buildings. A thick shield of lead or many feet of earth or concrete would protect against most of the gamma rays but lead, for example, would be quite transparent to the neutrons. Except for the ground directly below the point of detonation, good protection would be afforded from the deadly radiation by a fairly deep tunnel shelter.

C—After the bomb has exploded, the only danger that persists is from the so-called fission products which fall out from the atomic cloud and from radioactivity induced in material close to where the bomb is detonated. The fall of radio active material from the atomic cloud depends on atmospheric conditions and it may occur over the city or it may occur many miles from the city. Such radioactivity is due to burned-out atoms (fission products) and it is composed of beta and gamma rays. Beta rays are essentially high-speed electrons and they can be absorbed in a few sheets of thin aluminum. Gamma rays, on the other hand, are extremely penetrating X-rays and require several inches of lead to filter them out. Both rays are dangerous to human tissue. Perhaps the beta rays are the most insidious for they are more difficult to measure than gamma rays and, therefore, are sometimes overlooked even when present. No neutrons are present after the first few seconds of the blast.

D—Should the bomb be exploded close to the ground or to tall buildings, then considerable radioactivity is produced in this material by the action of the neutrons in passing through it. Such radioactivity is said to be " induced " in the material. Certain elements such as sodium (as in table salt) are easily made radioactive. Each element so activated by neutrons thereafter " decays " by emitting beta and gamma rays; the time taken by the various elements to decay

varies from element to element. Depending upon the exact circumstances of the bombing, the ground below the point of detonation will be radioactive for a length of time varying up to several months' duration. For example, if an atomic bomb were smuggled into the basement of the City Hall and then detonated, it would be many weeks before that area could be safely re-entered and many months or even years before it was safe for rehabilitation.

E—Using radio-active materials which accumulate in the manufacture of plutonium, it would be possible to make a lethal gas of finely dispersed fission-products which could be deposited on an unsuspecting city. Such a radio-active gas attack on a city would panic the entire populace unless the city were provided with radiation-measuring instruments to detect the activity. Even the rumour of such an attack would send a city's populace into flight if it were not reassured by on-the-spot instruments capable of measuring the radio-activity. Incidentally, there are very few such instruments now in " City X " and fewer still which can measure beta rays.

F—It should be emphasized that one cannot rely on the senses to detect the presence of radio-activity. Neutrons, beta and gamma rays can be present in lethal intensities without any immediate effect on the senses. To be sure, after a while there is a decided effect noted by the body but by that time it is too late for the victim to get away from the radiation. Scientists do not understand the fundamental means by which penetrating radiation produces changes in human tissues, but they know what happens to such tissue after it is exposed to radiation. As a result of exposure to intense radio-activity, certain physiological changes take place in the body. Symptoms of radiation damage include nausea, vomiting, general debility, sustained fever, loss of body hair, erythema (redness of the skin from capillary congestion), loss of appetite, and a decrease in the white blood cell count. These symptoms may appear soon after the exposure or in a few weeks. For example, epilation (loss of hair) may occur within a few days or within a few weeks. Exposure to radiation accompanied by injury from burns or falling debris may result in the death of a person even though neither the radiation injury nor the burn would of itself have caused death. There is very little that medical science can do for persons suffering from radiation damage and almost nothing it can do if the victim is exposed to more than a certain critical dose of the rays.

14. Zones of Damage from Radioactivity

To return to discussion of hypothetical A-bombing of " City X ", the necessary facts about radio-activity have been presented and the specific radiation damage inflicted upon the populace can now be considered.

All persons living within a radius of about 1 1/3 miles of the epicentre would be exposed to a lethal dose of radiation provided they were not shielded by thick brick or concrete walls. A wood frame wall offers little shielding from this radiation. Therefore most of the people surviving the combined effects of fire and blast in this area would probably die within a few days or weeks from the ffects of the penetrating radiation.

Those living in the zone from 1 1/3 miles to 2 miles from the epicentre while not receiving a lethal dose of radiation, would receive a considerable exposure that would complicate their recovery if they suffered any other injuries. Many would show obvious signs of radiation damage, such as loss of hair, but they would later recover and live apparently normal lives.

Outside of the 2-mile radius, there would be no effect from the primary flash of radiation, but it is possible that a fall-out of radio-activity would occur. If so, varying intensities of radio-activity might be found ranging from harmless to dangerous amounts.

Village Y would lie directly in the favoured path of the fall-out and if conditions were such that a rain storm occurred carrying down vast quantities of radio-activity with it, then the entire populace of Village Y and surrounding territory would have to be evacuated quickly.

It will be recalled that in the case of the New Mexico atom-bomb test, some of the atomic cloud settled out miles away from the detonation point and cattle in the path of this fall-out later were found to have white backs where some of the radio-active particles adhered.

15. Total Casualties

In summing up the supposed atom-bombing of " City X ", one can most readily realize the terrific striking power of the new weapon by estimating the total casualties caused by the explosion—about 100,000. Of these, about 50,000 would result in fatalities. The number of fatalities would run as high as this because of the lack of proper medical facilities at the time they are needed most, *i.e.*, the day of the explosion. At Hiroshima there were only a few hospitals in usable condition out of about 50. Of 1,780 nurses, about 100 were available for duty after the explosion.

The staggering figure of 100,000 casualties would mean that every family in the city would be directly affected by the explosion. Many civic leaders, key industrialists, and thousands of skilled craftsmen would succumb to the disaster. Thus while the Section A steel plants would still be intact and outlying factories would be undamaged, the city would require many months before it could rebuild the bombed-out area, replace personnel, and repair public service throughout the stricken community. " City X " would have been effectively knocked out by one bomb!

16. Defence Against Atomic Attack

There are many who will ask if there is not a means of counteracting the atom bomb. To that question the answer is simple. The atom bomb is a new type of high explosive and as such it is the same as any other high explosive in that you can protect against it only by deflecting it from its trajectory or by blowing it apart before it reaches its object. There is absolutely no mysterious mechanism in the bomb that one can detonate prematurely by radio waves, ultrasonics, or other means.

The use of guided missiles may do much to enable one to seek out and explode atom bombs before they reach their objectives, but it is difficult to conceive of this process being perfected to the point where it will guarantee that no bombs will get through the defence.

Furthermore, since warfare of the future promises to be one of split-second timing in which the element of surprise will be of paramount importance, adequate defence would require constant on-the-trigger vigilance by every nation. In an atomic war, if even a few minutes are required for alerting defensive forces or for getting administrative decisions, the war may be over before the defence went into action.

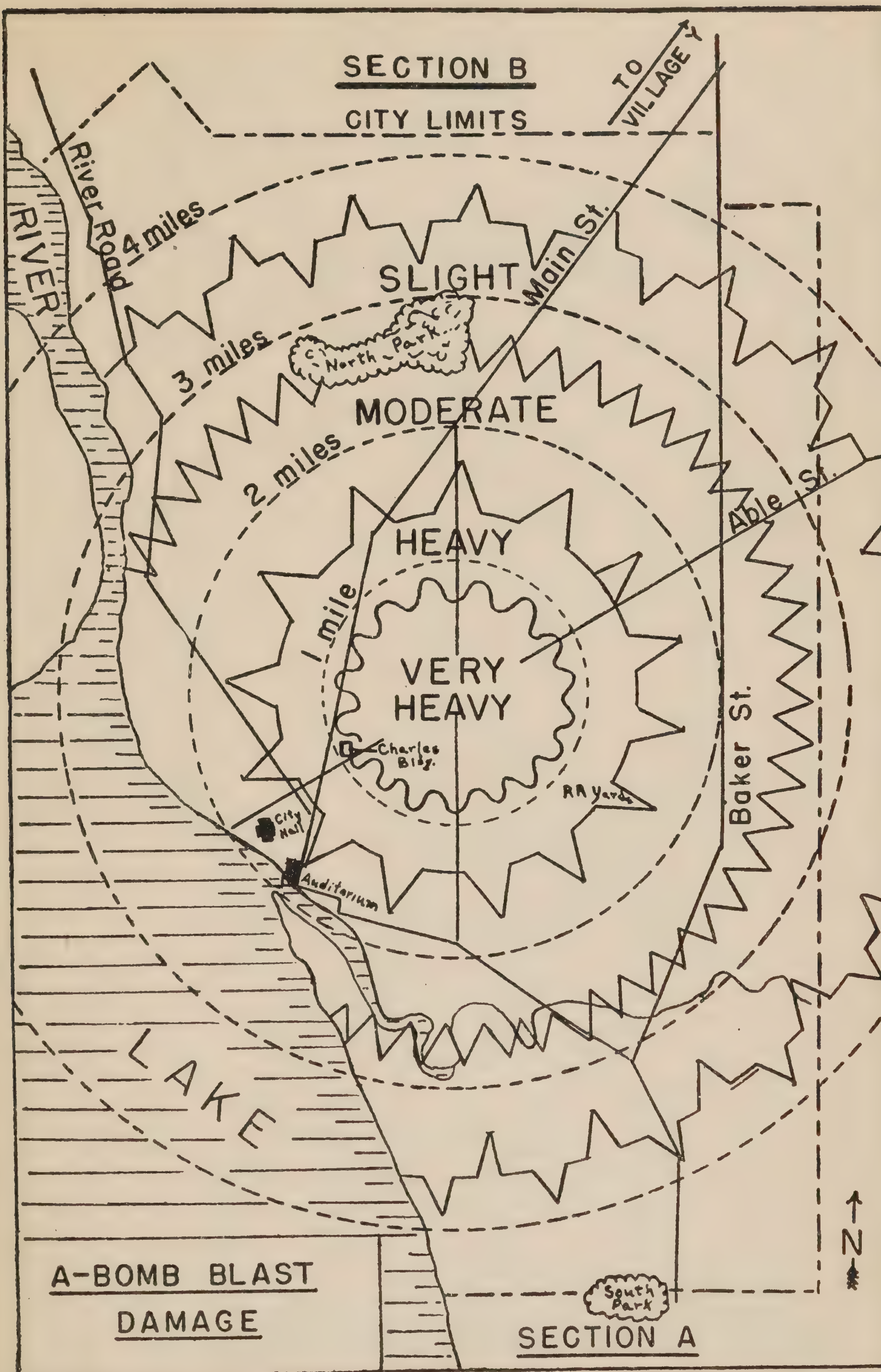
The danger of insidious warfare using sabotage with radio-active materials, planting atomic bombs in cities or harbours is not to be minimized.

If a great world power is willing to sink enormous amounts of money, resources and manpower into an all-out effort, it probably can produce bombs of effective design within 15 years, perhaps in less than 10. The United States has already given out a large amount of information about the atomic bomb which will reduce considerably the time required for another nation to make it.

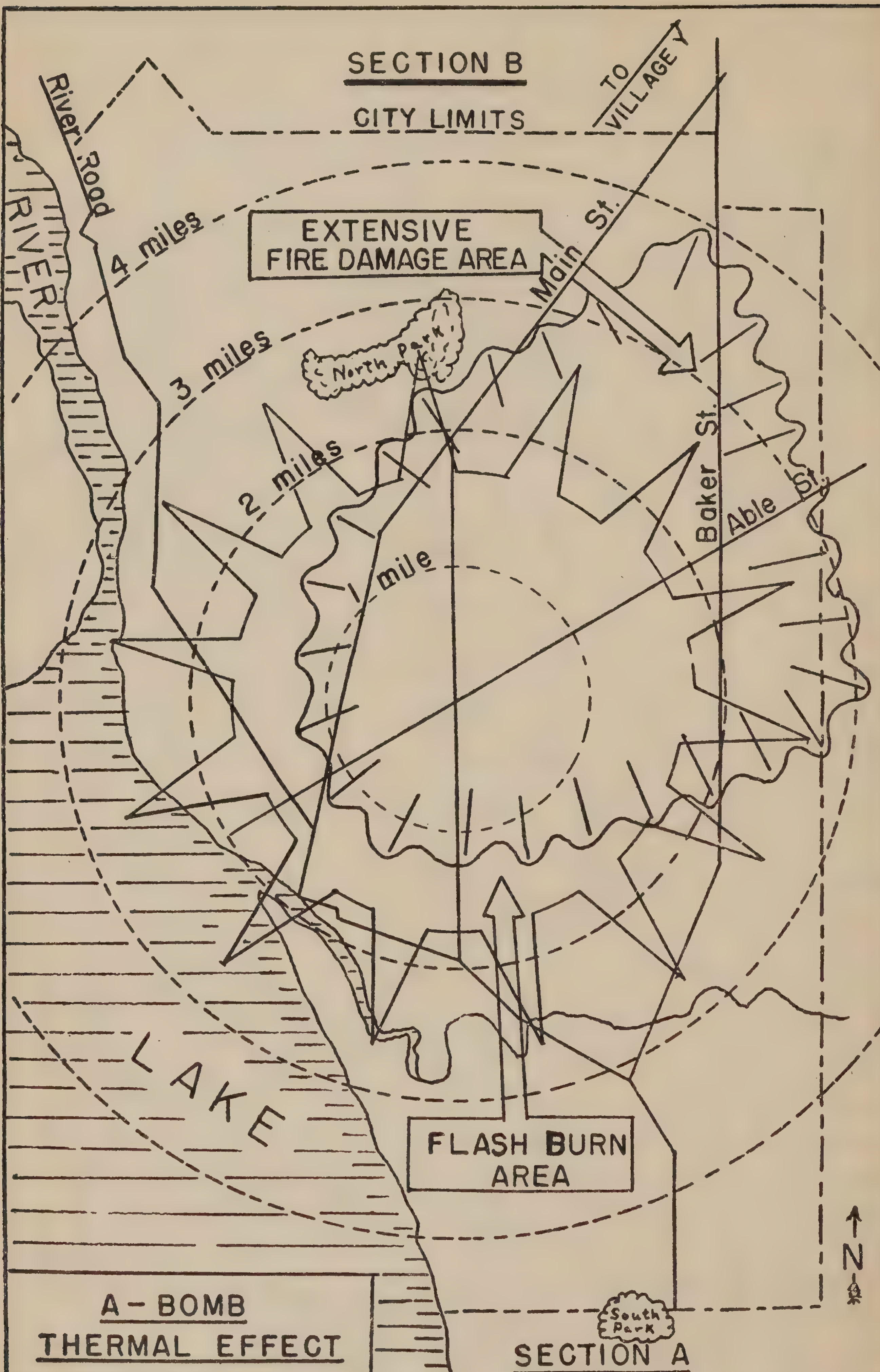
There are many preventive measures a city can undertake to minimize damage from atom-bombs, for example, decentralization of vital facilities and utilities, proper city planning with adequate allowance for fire lanes and fire-breaks to minimize fire-damage. The building of strong reinforced concrete structures for vital industries, construction of tunnel shelters, and many other measures will all tend to make a target city less desirable as a target.

In many cases, the cost of such defensive measures would be prohibitive and in the final analysis, they are futile. In the few years which are left before other nations have atom bombs of their own, it is useless as well as economically unsound to try to convert our cities into decentralized underground strongholds. The effect that such action would have upon civilian morale cannot be estimated.

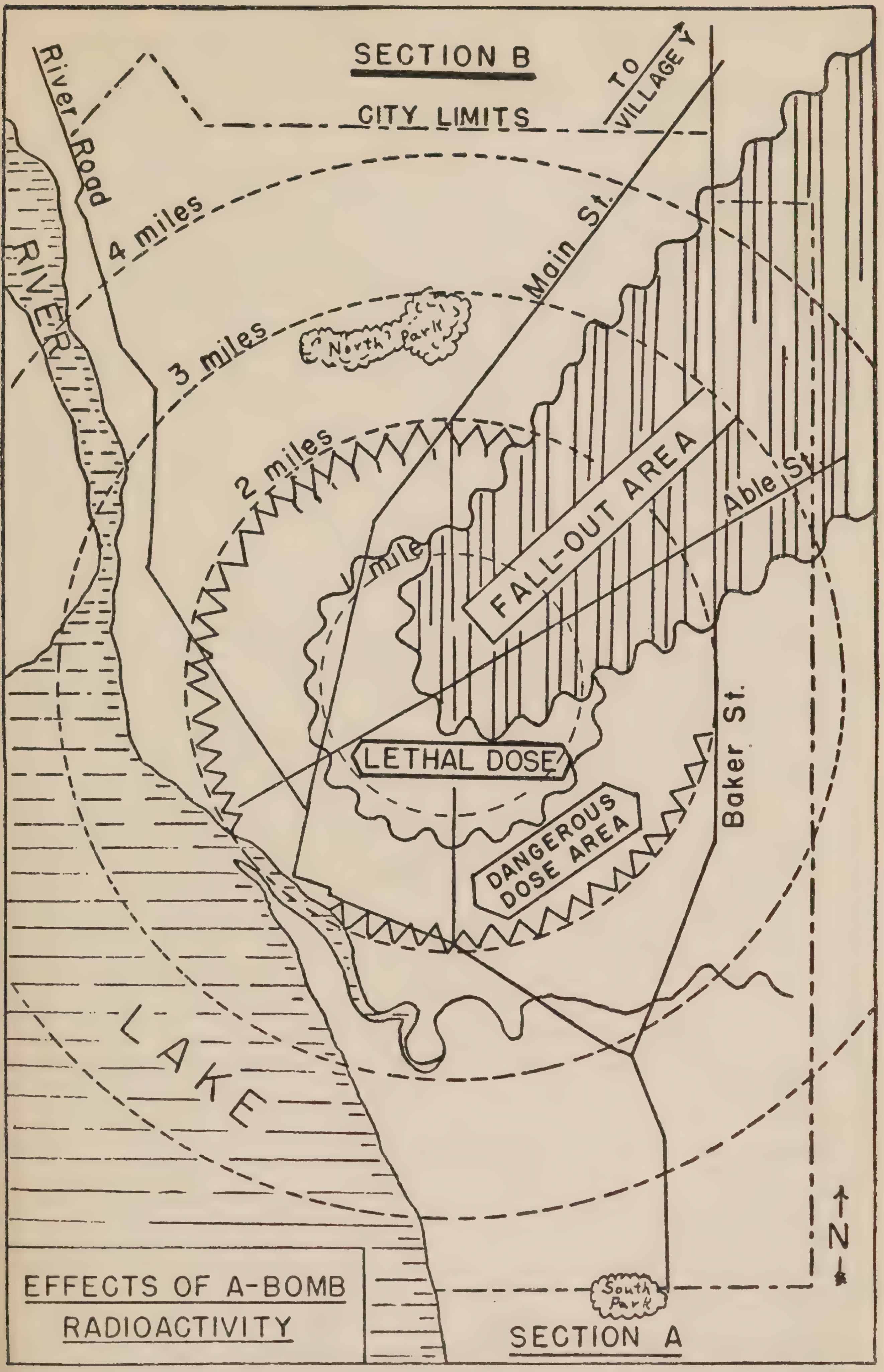
In spite of the enormous destructive power of the atomic bomb, the new weapon is not an absolute weapon. It remains to be seen just what place the weapon will have in military strategy.


SECTION B
CITY LIMITS
TO VILLAGE
RIVER
River Road
4 miles
3 miles
2 miles
1 mile
SLIGHT
North Park
Main St.
MODERATE
HEAVY
VERY HEAVY
Able St.
Charles Bldg.
RR Yards
City Hall
Auditorium
Baker St.
LAKE
A-BOMB BLAST DAMAGE
South Park
SECTION A
N

Map 1


SECTION B
CITY LIMITS
TO VILLAGE Y
River Road
RIVER
4 miles
3 miles
2 miles
1 mile
EXTENSIVE FIRE DAMAGE AREA
North Park
Main St.
Baker St.
Able St.
LAKE
FLASH BURN AREA
South Park
SECTION A
N
A-BOMB THERMAL EFFECT

Map 2


SECTION B
CITY LIMITS
TO VILLAGE
River Road
RIVER
4 miles
3 miles
2 miles
1 mile
Main St.
North Park
FALL-OUT AREA
Able St.
LETHAL DOSE
DANGEROUS DOSE AREA
Baker St.
LAKE
N
South Park
SECTION A
EFFECTS OF A-BOMB RADIOACTIVITY
47 7759

Map 3

IV

BIOLOGICAL EFFECTS OF ATOMIC EXPLOSION

1. General

Biological effects of ionizing radiations were first observed a few months after the discovery of X-ray in 1895. The effect of radiation on the human skin was the first indication of any biological effect of X-ray and radium. Becquerel was among the first to make this observation. He carried a small vial of radium in his vest pocket and developed a burn to the underlying skin. Within a few months X-ray dermatitis of the hands was very much in evidence among those working with X-rays and radium.

During the decade following 1896, X-ray was used as a therapeutic measure on almost every known disease. Needless to say, the results were disastrous.

From 1903 to 1905, the marked radiosensitivity of the blood-forming organs and reproductive organs of animals sounded the first warning that other than skin effects were occurring. Since that time, thousands of papers have appeared in the literature describing radiation effects on animals and plants. As a result of all this activity we have:—

(*a*) A large mass of qualitative information concerning various radiation effects.

(*b*) A considerable amount of quantitative information connecting the amount of radiobiological effect with the amount of radiation producing the effect (dose-effect relationship).

(*c*) Considerable knowledge of the extent to which the dose-effect relationships are influenced by various physical, chemical and biological factors.

(*d*) Very little understanding of the mechanism by which radiations produce biological effects. Many theories have been advanced as to just how a cell is affected by ionization radiation, but the answer is still unknown. Until this problem is solved we are groping in the dark for an answer to radiation sickness. Some believe the effect is due to a change in the nuclear protein of the cell—some chemical change which prevents the normal interchange between the nucleus and the rest of the cell. Others believe that certain toxic products are produced which in turn cause the death of the cell. Still others believe that the results are caused by an interference with the permeability of the cell membrane, thus interfering with the normal exchange of fluids, etc.

2. Generalities Concerning Biological Effects

(*a*) Ionizing radiations produce not one but many different effects, even upon the same species of cell or organism.

(*b*) Practically all radiation effects are either definitely injurious or of no value to the individual or species from the standpoint of survival or competition.

(*c*) Injurious effects vary widely in their severity.

(*d*) Some injurious effects are permanent, some temporary.

(*e*) Effects of radiation are not limited to the irradiated individuals. Certain effects may appear in the descendants.

(*f*) Injurious effects are sometimes turned to practical use, namely; the radiotherapy of malignant growths. A procedure which is successful when a sufficiently injurious effect can be produced in the tumor, with an amount of radiation which produces no serious permanent damage to the normal tissue unavoidably exposed at the same time. An interesting paradox is presented here—although radiation is widely used to destroy malignant growths, under special conditions the same agent may induce malignancy.

3. General Course of Radiation Effect

Irradiation.—This involves the absorption of the kinetic energy of fast electrons of atomic nuclei which may originate in a number of ways either inside or outside the biological object. An interesting aspect of the energy absorption is the small amount which suffices to produce significant effects. For instance, most cells and organisms are killed by an X-ray dose of 10,000 r. In a soft tissue this corresponds to an energy increment of only about ·02 cal/gm: If the same amount of energy were added as heat, the resultant increase in temperature would, of course, result in no harmful effects.

4. Biological Effects Observed

A single cell consists of several microscopically distinguishable parts, which differ in chemical make-up. Since, under most conditions, all these parts are irradiated simultaneously at random, it is not surprising that many effects may sometimes be observed in the same cell. Some of these effects can be directly observed by various microscopic techniques; for instance, chromosome breaks, increased granularity of protoplasm, change in affinity for various stains, cytolysis, swelling of the nucleus, or of the entire cell, etc. Less direct physical methods reveal other effects, such as changes in the viscosity of the protoplasm, or in the permeability of the cell membrane. It seems probable that only a small fraction of the cellular effects produced have yet been observed.

The complexity encountered in the observation of cellular effects is increased many-fold when we attempt to observe or analyse the effect on many celled-organisms. Here we irradiate many different types of cells and tissues, each of which may exhibit its own peculiar pattern of effects. This becomes further involved with the possibility of a radiation effect on one tissue producing an indirect effect on others.

The latent period is really a misnomer. It is the period which elapses between the time the tissue is irradiated and the effects manifest themselves. Obviously, this period is not latent, but one during which numerous successive changes are occurring, which eventually lead to the change finally observed. Concerning the nature of these intermediate changes we are in practically complete ignorance. The radiation sensitivity of the various body tissues in order of sensitivity are listed:—

(*a*) Lymphoid tissue, bone marrow, blood lymphocytes, lymph nodes, Peyers patches.
(*b*) Polymorphonuclear leukocytes.
(*c*) Epithelial cells:
  1. Gonads and ovaries;
  2. Salivary glands;
  3. Skin and mucous membrane;
(*d*) Endothelial cells, blood vessels and peritoneum.
(*e*) Connective tissue cells.
(*f*) Muscle cells.
(*g*) Nerve cells.

Contrary to the more accepted principle of pharmacological action, the tissues which are less specialized in function tend to be more vulnerable to radiation. The highly complex cells of the nervous system are apparently little affected by ionizing rays. At the other extreme, the primitive cells of the reproductive or lymphatic systems are extremely vulnerable.

5. Cellular Environment

Whether the effect of ionization is a direct one, taking place within the cell, or an indirect one, resulting from alterations in the environment, is still a matter of conjecture—both mechanisms may be active.

As an example—diminished effect of radiation on extremely radio-sensitive tissue when subjected to decreased oxygen supply. Cold—freezing definitely decreases radio-sensitivity.

6. Reversibility of Effects

By reversibility is meant the return of a tissue to its previously normal state after exposure is discontinued. The reversibility of any specific effect is dependent upon the separative or regenerative properties of the tissue. Some tissues such as skin, the blood-forming elements, membranous linings of body cavities or glands, and peripheral nerves are endowed with a special mechanism for repair and regeneration. Other tissues, such as muscle, brain and certain structures of the kidney and eye have no provision for regeneration. In them, repair is by the formation of a scar, which does not take over the function of the original tissue it replaces. Such effects are irreversible.

A tissue which has returned to apparent normal function following radiation damage may not, however, sustain repeated damage and be able to regenerate.

Skin previously irradiated which has apparently returned to normal must be carefully observed and a repetition of the injury must be avoided.

7. Measurement of Effects

In general, the individual cells or organisms in an apparently uniform sample do not respond equally to radiation. This makes it impossible to measure effects in terms of severity or injury to a single specimen, and forces us to use statistical methods in measuring any given effect.

The most convenient way of measuring the majority of effects is to set up as criterion of effects some occurrence which may be classified simply as present or absent, such as inhibition of cell division, failure to grow, or death. Graded doses are given to various groups of biological objects and after the exposed cells or organisms have been scarred or injured or uninjured, the percentage of uninjured ones is plotted against the dosage. This yields a survival curve. The term survival here denoting the ability to perform a certain normal act in spite of irradiation.

8. Effect of Species on Radiosensitivity

It is repeatedly found that if the same biological effect be studied in different species, even closely related ones, the doses required to produce the same amount of effect may vary to a significant degree. This can best be illustrated by recent data on three week survivals of various laboratory animals.

The doses of 200 kv-X-rays required to kill 50 per cent. of the animals were as follows:—

Mice	500 r
Guinea Pigs	250 r
Rabbits	825 r

This species difference is very troublesome in a practical way. We very much need quantitative information concerning radiation effects on humans. It would be very fortunate if we could carry out drastic experiments on laboratory animals and draw therefrom quantitative conclusions concerning man. Species variations reduce such conclusions at best to a semi-quantitative status.

9. Influence of the Rate of Irradiation on Effectiveness

The influence of the rate of irradiation on effectiveness may be divided into three categories:—

(*a*) In the production of many biological effects, a given dose produces the same amount of effect, regardless of the rate at which it is delivered. (Among genetic effects, at least some fall in this category.)

(*b*) In a few cases, it has been reported that a given dose becomes effective if the rate of delivery is decreased. This has been explained by postulating that, during a prolonged irradiation, the radiosensitivity may increase.

(*c*) For the remainder of the biological effects (perhaps 50 per cent.), the effectiveness of a given dose increases as the rate of exposure decreases. This has been explained by an assumed decrease in radiosensitivity or probably more logically on the assumption of a recovery factor. Most of the known injurious effects on mammals fall into this category—which is very fortunate. Otherwise, the daily tolerance dose would have to be set low enough so that it would be impossible for an injurious dose to accumulate during the maximum employment of an individual in the vicinity of sources of radiation.

10. Distribution and Penetration of Radiation

Whether or not a particular radiation will produce damaging effects and also the nature of these effects, depends upon the ability of the radiation to reach the tissues in question.

Although alpha particles are highly ionizing and destructive, their range of action in tissue is small, approximately 0·1 mm. But when material which is alpha radioactive is deposited within the body in a vulnerable organ (bone marrow) the limited range of the alpha particle is no longer so great a factor and severe maleffects will occur.

Similarly, low energy beta particles as from I-131, Sr-89 cannot penetrate the skin to an effective depth, but the same beta emitter in the bone, lung or thyroid in sufficient quantity may be most injurious.

High energy gamma has a much less degree of ionization than an alpha particle, but has the ability to penetrate into more vulnerable regions of the body.

Comparison of relative quantities of various qualities of radiation required to produce erythema of the skin:—

Radiation Range	*Exposure to Produce Erythema*
Grenz Rays	100 r.
100 kv X-rays	350 r.
200 kv X-rays	600 r.
1,000 kv X-rays	1,000 r.
Gamma rays (Ra)	2,000 r.

11. Blood

It is fortunate for our purposes that the circulating blood in man is available as an index of over-exposure to radiation. Radiation affects the tissues which form the blood, namely, bone marrow and lymphatic system. Observation of the blood count thus reflects injury to the blood-forming tissues. The effect is rapid in severe over-exposure; alteration in a blood count may be observed within an hour after total body exposure. In exposures to small quantities of irradiation, it is difficult to detect any significant changes in the count. Anæmia is a late—not early—sign of irradiation, and by the time it is manifested the bone marrow is in a precarious condition. Radiation induced anæmia is extremely serious and often fatal. Leukopenia or an inversion of the normal neutrophil-lymph ratio are early objective signs of over-exposure.

12. Reproductive Organs and Germ Plasm

The elements of the reproductive organs which may be injured are (*a*) the progenitors of the sperm and (*b*) the genes which make up the chromosomes and transmit hereditary factors.

(*a*) Reproductive organs.—Sterility can readily be produced by irradiation. Dose necessary for the male is about 800 r and in the female about 600 r. Dogs that have been exposed to 0·1 r per day for 2½ years—a total of 66·5 r are showing changes in the spermatocyte.

(*b*) Genetic injury.—In 1927, Muller demonstrated that the mutation rate of the fruit fly could be accelerated by exposure to X-rays. Bragg and Little and Snell have produced radiation-induced mutations in mice. Radiation increases the rate of appearance of the common mutations which are known to occur spontaneously. It produces the uncommon ones rarely. Single exposures of 30 to 40 r will double the mutation rate in the fruit fly. Single doses of 500 r are required to produce mutations in mice, but these are produced in far lower incidence than in the fruit fly.

There is a linear relationship between dose and increase in mutation rate. The cumulation of exposure is thus additive. Furthermore, the magnitude of the effect is independent of the wave length and dosage rate of exposure.

Mutations, whether spontaneous or produced by radiation, are about 90 per cent. lethal or sub-lethal. This means that the offspring does not survive the gestation or hatching period, or dies shortly thereafter. The lethal mutations are dominant or recessive. By dominant is meant that, for the exposed parent organism, the lethal effect appears in some of its direct offspring. By recessive is meant that the effect might appear only in some succeeding generation of the radiated subject. In man, it would appear in near descendants only should cousins or near relatives intermarry. It has been calculated from the laws of genetics that some 5,000 years would be required for a mutated gene to meet another mutated gene descended from the original mutation. This would indicate that we need not be too concerned about the recessive deleterious effects of mutation.

The variable mutations (about 6 per cent. of all mutations whether spontaneous or produced by radiation) are about 95 per cent. deleterious ones. Of these, the majority (about 96 per cent.) pertain to other than sex chromosomes. The remaining are sex-linked mutations appearing in the sons of the

daughters of the sperm carrying the mutated gene. The spontaneous rate of appearance of these dominant deleterious yet viable mutations is about 1:2,700. It has been calculated that an accumulated dose of 300 r will raise the probability to 1:230.

As stated above these figures were obtained from studies in the fruit fly and mouse. Actually very little is known about genetics in man.

V

MEDICAL EFFECTS OF ATOMIC EXPLOSION

Medical effects from the atomic bomb may roughly be divided into three categories as follows:—

1. Trauma.
2. Burns.
3. Radiation Injury.

1. Trauma.—Inflicted by the mechanical force of the explosion, either as blast or indirect trauma due to flying debris. As in the case of the bombing of Britain, the latter was much more important. The atomic explosion differs from an ordinary bomb blast in the wide compass of its range. No one was closer to the bomb than several hundred metres. At that distance the peak pressure must already have fallen, and its duration must have greatly decreased in comparison with what it was in the centre. The explosion did not have the trip hammer blow effect of high explosive, but was rather like a sudden violent gust of air which lasted for a brief but appreciable period.

Japanese medical observers on the spot could not find any cases of direct damage to the internal organs by the blast. Necropsy of the early cases shows no typical evidence of blast damage to the lungs. Many individuals reported having lost consciousness temporarily with no history of direct trauma to the head. Observations of Zuckerman (British report) tend to discount cerebral concussion resulting directly from the blast. A report shows the total of 17 ruptured eardrums at Hiroshima and 22 at Nagasaki. According to the British investigators there is a great variation in the intensity of the blast pressure which will result in the rupture of the eardrums in man. In explosions where persons were subject to pressures estimated at between 45 and 100 pounds per square inch, less than one-half of a small group suffered rupture of the tympanum. The drum may, however, rupture under pressures as low as two to four pounds in excess of atmosphere. Facts of acceleration of pressure may also be important in determining the incidence of blast effect on the biological target.

(*a*) INDIRECT EFFECTS OF BLAST CAUSED BY FALLING WALLS, FLYING GLASS, ETC. Windows were broken as far away as Kuro. 20 km. The radius of complete collapse of the natives' wooden buildings was 2·4 km., almost symmetrically distributed about the centre. The incidence of mechanical injury is about 60 per cent. between 500 and 1,250 metres. It is only beyond 2,700 metres that the incidence of mechanical injury begins to fall off rapidly. Even at 4,500 metres, the incidence of mechanical injury in the survivor group is still 14 per cent. Fatal injuries, however, are almost entirely in the zone of complete destruction.

Those indoors in heavy buildings, surprisingly, show a higher incidence of injury than those remaining in native Japanese buildings. Since most of the injuries were inflicted by flying glass and the concrete buildings having more glass than those of the native type, the explanation of the paradox is

clear. Furthermore, this ratio of injury applies only to non-fatal injuries in survivors. It is assumed that the *total* mortality from immediate trauma is higher in the Japanese buildings than in the concrete buildings at the same distance, the reason being that over a wide area of impact the Japanese buildings collapsed from blast while the concrete buildings generally retained their structural integrity. Exactly how much of the total mortality was caused by the traumatic factor will never be known, because within one-half hour following the blast both cities were swept by fire before rescue operations could be instituted. Consequently, even though mechanical injury was not directly responsible for death, it probably contributed vitally to the actual mortality. This accounts for the low incidence of severe forms of injury amoung the survivors.

The British estimate that a bomb similar to the one used at Nagasaki if exploded at the same height over a city such as London would cause complete collapse of normal buildings for a distance of 3,000 ft. from zero point, damage all houses beyond repair out to a distance of one mile, render houses uninhabitable without extensive repairs up to a distance of 1½ miles, and would render houses untenantable without immediate repairs out to a distance of 2½ miles. Over London the bomb would completely wreck 30,000 houses, badly damage 35,000 and damage from 50,000 to 100,000. Based upon a density of population of one person per 1,000 sq. ft., the bomb would kill 75,000 people. Compare this with a 500 lb. bomb dropped in the same area which would cause a mortality of six people and a block buster which would cause a mortality of 30 people.

(*b*) TYPES AND MECHANISMS OF INJURY FROM ONE GROUP OF PATIENTS AT A MILITARY HOSPITAL WERE AS FOLLOWS:—

Fractures	11·5 per cent.
Contusions	53·8 per cent.
Lacerations	34·7 per cent.

Flying glass was the cause of the greater percentage of lacerated wounds. The fragments were so small that in many cases clothing was sufficient to protect the body. In one case, at 1,000 metres, the patient was struck by glass fragments which, even though it did not penetrate his trousers, struck with sufficient force to pierce the skin of the upper portion of the bared torso and produce an injury.

2. Burns.—The burns that occurred may be classified as " flash burns ", which are the result of the direct action of radiant energy, and flame burns. The latter were relatively rare, for the reason that it took some time, perhaps one hour as stated above, for the fires that were started following the blast to spread within the city. Consequently, those who did not escape were burned to death.

The radiant energy covered the entire width of the spectrum, which resembled that of the sun. Let us now consider only the ultra-violet, visible light and infra-red rays. None of these has a high degree of penetration, so that any solid object, such as clothing or even leaves, was sufficient to produce a shadowing effect (outline of the man who was in the direct line of rays projected upon the asphalt of Bantai Bridge), only surfaces directly exposed to the rays were affected by them and thus results the so-called " profile " burns. The wood of dark coloured telephone poles was superficially carbonized at 3,000 metres from the centre. From the data of Ashe and Roberts, a temperature of 4,000 degrees Centigrade acting for approximately 0·5 seconds is necessary to produce a second degree burn. It appears that the injurious agents causing flash burns were of extreme

intensity but lasted for a very short duration. Burns were remarkably common among those indoors, as it was summer and many of the windows were open. Burns were of no significance beyond 4,000 metres. Beyond 3,000 metres few burns required treatment and were merely emphasized by erythema. Fifty-three per cent, of the deaths attributed to burns died within the first week and 75 per cent. of the total within two weeks.

Symptoms associated with the burns varied from case to case but tended to follow a fairly definite pattern. In individuals close in, both burns and blisters were apparent in five minutes. Further out, in the vicinity of 1,500 metres, burns appeared in two hours' time and the blisters in from four to six hours. Within 2,000 metres, the burns appeared in about three hours and blisters after an elapse of ten hours. However, in one patient at 2,000 metres there was vesication within ten minutes.

(*a*) EFFECTS OF RADIANT ENERGY UPON THE EYE.—Direct injuries to the eye were remarkably few. Only a few palpebral burns were noted. The shadowing effects of the supra-orbital ridges and the blink reflex helps to explain this finding. Almost all of the patients had temporary amblyopia which lasted for an average of five minutes. A few patients had conjunctivitis and keratitis. Only one patient with a permanent scotoma from perforation of the macula was reported. Two patients developed traumatic cataract following contusions of the eyeball. A slight reduction in the transparency of the cornea was observed in some but they presented no subjective difficulties. One patient was so blinded by the flash that he was unable to distinguish light from dark for approximately two days but he made a complete recovery.

(*b*) KELOID CHANGES.—Keloid changes appeared frequently and in many cases are extreme. According to the Japanese physicians, the incidence of keloids is not a characteristic of race and they attributed its large incidence to the extreme temperature. However, it has been noted that where skin flaps were removed for plastic surgery, healing resulted in keloid changes. A follow-up of the " keloid problem " is being made by the Atomic Bomb Casualty Commission.

(*c*) PIGMENTATION AND DEPIGMENTATION.—Among the striking features of burns were the changes in pigmentation. At a distance of approximately 2,000 metres beyond centre, the pigmentation was extreme and resembled a walnut stain. (Mask of Hiroshima). These burns were preceded by an intense erythema, which within a few days became increasingly pigmented. Surrounding the hyper-pigmented area was a sharp border in which was found a zone where there was even less pigment than normal skin. This zone represented an area where some melanophores had appeared to enter the hyper-pigmented tissue. This pigmentation began to fade only in a few cases at four months and in many cases still persisted after two years.

Depigmentation of the exposed skin occurred at distances less than 2,000 metres. It was not necessarily associated with the scarring of the skin. There is histological evidence that loss of pigment in the basal layers can occur, even though the epithelium of the surface is not destroyed. At the margins of the depigmented zones there was found a narrow band of increased pigmentation externally to which there was again a vaguely defined depigmented border as described above. In the area of depigmentation the erector pilorum muscles were not damaged.

(*d*) ETIOLOGY OF THE BURNS.—Certain features of the burns suggest the action of specific wave lengths, probably in the ultra-violet range. The

intensity of the pigmentation at 2,000 metres and the extreme depigmentation without destruction of the skin closer to the bomb is certainly an unusual result of thermal injury. It must be remembered that a relatively small quantity of air intervened between the patients and the bomb in comparison with the entire atmosphere and stratosphere which filters much of the ultra-violet from the sun. Gamma rays are not responsible for the sharply outlined pigmentary phenomena that have been described, since clothing would be no barrier to their action.

(*e*) PROTECTIVE EFFECT OF CLOTHING.—Clothing exerted a protective effect depending upon a series of inter-related factors that include:—

(1) Distance from the bomb;
(2) Colour and shade;
(3) Tightness of the clothing;
(4) Thickness and number of layers.

(1) DISTANCE.—A khaki uniform, coat and shirt worn together, were protective beyond 1,500 metres. Closer to the bomb, clothes were no protection. In some instances clothing actually caught fire and the resultant flame burns were among the most severe that were encountered.

(2) COLOUR AND SHADE.—Darker shades absorb more heat than lighter shades. The effect of selected absorption in many cases was remarkable. At 1,600 metres in the case of a white rayon shirt with a pattern of dark blue polka dots, 2 mm. in thickness and 1 cm. apart, the polka dots were burned in the line of the rays but the intervening white material was undamaged. Extremely interesting is the effect upon cotton cloth with flower pattern in a light pink background. The flowers were dark red roses with leaves of varying shades of green. Some of the flowers were entirely burned out, others showing only scorching of the darker portions of the leaves and petals, while the intervening material showed no effects.

(3) TIGHTNESS.—Where the clothing was more tightly stretched over the scapular and deltoid regions, burns were much more likely to occur.

(4) THICKNESS AND NUMBER OF LAYERS.—The protective effect of the seams and double layer effect of the folded-over collar demonstrated the protective effect of the thickness of clothing.

3. Radiation Injury.—The pathogenesis of the signs and symptoms will first be considered and then will follow an outline of the most common clinical syndromes:—

(*a*) SKIN: Epilation was frequently observed among persons who had been close to the bomb and who had survived for more than two weeks. At 500 metres the incidence was approximately 75 per cent. and fell off sharply at 1,250 metres. The time of the onset of epilation reached a very sharp peak between the 13th and 14th days after the bombing. Peak for males and females coincided. The hair suddenly began to fall out in bunches upon combing or general plucking, or it was found in considerable quantities on the pillow in the morning. This process continued for one of two weeks and then ceased. In most cases the distribution was that of an ordinary baldness, involving first the frontal and then the parietal and occipital regions, and sparing the temporal regions and scruff of the neck. The eyebrows and even more so the eyelashes and beard were relatively resistant. In one group of patients coming to autopsy, 48 had epilation of the head, 8 of the axilla, 6 of the pubic regions, 4 of the eyebrows and 2 of the beard. Complete epilation is not necessarily correlated with a bad prognosis. On the other hand, 14 per

cent. of all individuals who died of radiation effects at approximately the fourth week had no epilation. It can be assumed that such cases received some shielding effect such as concrete buildings, thereby filtering out the softer rays, with death resulting from the hard penetrating rays which have little effect upon the skin.

Even in severe cases, the hair had begun to return by the middle of October and two or three months later had fully returned. In no case reported was epilation permanent.

(*b*) ORAL AND GASTRO-INTESTINAL TISSUES: In many patients severe nausea and vomiting occurred as early as 30 minutes following the detonation. In other cases, it did not occur until the next day. Thirty-two per cent. of the individuals within the first 1,000 metres and 23 per cent. who were between 1.100 and 1,500 metres suffered from vomiting on the day of the bombing. The incidence fell sharply to 6 per cent. at 2,000 metres. Diarrhœa, sometimes sanguineous, occurred within the first few days in many patients. Membranes, similar to the type found in agranulocytosis angina, occurred throughout the gastro-intestinal tract.

(*c*) GONADS: Histologically, radiation effects on the testes were discernible as early as the fourth day and were profound in all fatal cases who had been within 1,500 metres of the bomb. It was obviously of interest to study the sperm counts in the survivors. Only three of the 23 patients studied who had been within 1,500 metres had a count in excess of 40,000 (lower limit of normal); of 39 who had been within 2 km., 13 had counts below 40,000. According to Macomber and Sanders, it is unusual for pregnancy to occur if the spermatozoa count is below 40,000. Several of the patients complained of a loss of libido or even loss of potency following the bombing. According to the Japanese physicians the return to normalcy has been slower in the male than in the female.

(*d*) OVARIES: Histologically, the ovaries showed less striking changes than the testes. During the war years in Japan, there was a high incidence of amenorrhea, increasing from 4·3 per cent. in 1932 to 12 per cent. in 1944. In 1944 the incidence among 316 nurses of the Tokyo Imperial University was 13.3 per cent. According to the Japanese gynecologists, this was due to malnutrition, overwork, and anxiety associated with bombing. Thirty-six per cent. of the women in Hiroshima and 29 per cent. of the women in Nagasaki, between the ages of 15 and 49, who were within a distance of 5,000 metres experienced menstrual disorders. The majority of these had one normal period following the bomb and had cessation for an average of three to four months. A year later no cases complaining of menstrual disorders attributable to the bombing were found.

(*e*) HÆMATOPOIETIC SYSTEM: In persons exposed to radiation, the lymphoid and hæmatopoietic tissues underwent rapid necrobiosis. According to the Japanese the effect on the blood was biphasic. The lymphocytes dropped immediately and reached their low point in about five days. A few days later the granulocytes began to drop and about the same time the lymphocytes began to recover. About the same time the reds began to fall and about the end of the third week in many cases there was a recovery of the lymphocytes with a marked decrease in granulocytes and an associated anemia. However, in some cases as early as five days following the bombing white blood counts as low as 150 cells per cubic millimeter were reported. Specimen of vertebral marrow obtained after 10 days following the bombing showed an almost total loss of myelopoietic tissue.

(*f*) HÆMORRHAGIC ASPECTS: Involved in this are four factors, namely platelet factor, dietary factor, infection factor, and capillary fragility factor.

(1) Platelet factor.—In 14 cases dying between the fourth to seventh week, in whom platelet counts were available, only two were above 60,000 per cubic millimetre. Most of the cases ranged between 10,000 and 25,000. In all of these cases the bleeding time was increased, in some as long as 46 minutes.

(2) Dietary factor.—Needless to say vitamin C levels were low.

(3) Infection factor.—Specific bacteriological data were unsatisfactory. There were, however, cases of bacteremia demonstrated by streptococci and bacilli found in freshly fixed tissues derived from the bone marrow.

(4) Capillary fragility factor.—Capillary fragility was found in individuals at the fifth week and at that time seemed to run parallel to the white blood count.

(*g*) CHARACTERISTICS OF THE HÆMORRHAGIC PHENOMENA.—For convenience these will be referred to as purpura. In the skin, purpura was almost always manifested in patients dying from the third to sixth week, inclusive. Its incidence at various distances from the centre ran almost exactly parallel to that of epilation and fell off sharply after 1,250 metres. Purpuric spots tended to appear at about the same time as fever. Their peak is between the 16th and 22nd day, some five days later than the peak of epilation. Associated with their onset, there is an increased tendency to bleed from lacerations, fractures and burns. Healing of wounds was prolonged, coincident with the appearance of radiation sickness. The growth of granulation tissue stopped and not tendency to heal was shown. In those who survived, the granulation tissue improved following recovery from radiation sickness associated with the purpuric spots on the skin. After the onset of the purpura of the skin, hemorrhages were also found in the gingivæ and from the rectum, nose, urinary tract and respiratory passages in that order of frequency. The lungs are frequently involved in a necrotizing and hæmorrhagic processes.

CLINICAL SYNDROME

Patients who died of radiation sickness may be roughly divided into three groups as follows:—

1. PATIENTS WHO DIED WITHIN THE FIRST TEN DAYS.—In this group there was histological evidence of radiation effects upon the skin, gastro-intestinal tract, lymphoid tissue, bone marrow, gonads or ovaries, but these had not been clinically manifested. There was no epilation nor purpura. Patients complained of nausea and vomiting on the first day of the bombing, followed by anorexia, malaise, severe diarrhœa thirst and fever. Death ensued in delirium. Profound leukopenia was present. Temperature records in all these patients were remarkably similar. Usually between the fifth and seventh days and sometimes as early as the third day there was a step-like rise in temperature, usually continuing to the day of death. The earlier the fever, the more severe the symptoms and the poorer the prognosis.

A typical case: A 31-year old petty officer of the Japanese Navy was admitted to the hospital the night of 9th August. He was within 250 metres at the time of the bombing and suffered first degree burns to the back, neck and chest, contusions of the nose and right hand and an abrasion of the left

elbow. On the 12th August he began to complain of abdominal pain. nausea, anorexia, dizziness and diarrhœa, which reached a frequency of 15 stools a day. At the same time his temperature began to rise and gradually continue upward until the day of his death, 15th August, 1945. His blood count on 12th August, 1945, was 4·6 million red blood cells and 150 white blood cells.

2. PATIENTS DYING THE THIRD, FOURTH, FIFTH AND SIXTH WEEKS OR SURVIVING SEVERE SYMPTOMS.—In this group, the anatomical and clinical results of radiation attained their acme. Epilation is prominent, as is the hypoplasia of the bone marrow. The hæmorrhagic and necrotizing lesions are entirely comparable to those seen in aplastic anæmia and agranulocytosis, and occur in the gums, respiratory and gastro-intestinal tract. Petechiæ of the skin are almost always present. The sequence of symptoms is somewhat as follows:—

> In a typical severe case, the first evidence of the disease is nausea and vomiting on the day of the bombing, followed by a feeling of malaise. The patient then begins to improve and feels fairly well until about the beginning of the second week when epilation begins. A few days later he then again experiences malaise and a fever occurs, step-like in character. At approximately the same time pharyngeal pain may appear. Sanguineous diarrhœa is a prominent symptom. The leucocytes and platelets reach very low levels and there may be an anæmic and generally debilitated condition for a long period.

A typical case: A twenty-five year old soldier was at the 104th Garrison, approximately 1,000 metres, on the upper floor of a two-story Japanese building at the time of the explosion. Fragments of glass struck his right arm and shoulder, inflicting a laceration on the former and contusion on the latter. That night he slept in a field but he returned to the garrison on the 7th. Between the 10th and 14th, he worked on the East drill field and was able to march 15 km. Epilation began on the 20th of August but he continued to work. On the 27th he felt feverish and on the next day petechiæ occurred. He was admitted to hospital on the 30th of August. At that time he complained of malaise, headache and swelling of the gums. He had previously had malaise on the day after the bombing. The gingivæ continued to swell and on 4th September they were extremely painful. He had a sore throat on 1st September and had dysphagia on the 7th. Superficial ulceration of the angles of the mouth were noted and on the next day he had trismus. His temperature rose sharply on 1st September and attained 40·6 degrees centigrade. On the next day it began to fall and reached normal levels on the 14th of September. Petechiæ began to clear on 9th September and he was sufficiently well on 4th October to be discharged. He was next seen on 23rd October by members of the Joint Commission who found him at work on his farm. At that time he complained only of shortness of breath. His white blood count reached 1,400 in contrast with a low of 900 on 4th September.

3. GROUP 3.—In some individuals in whom the bone marrow fails to recover, the symptoms described in group 2 continue and the patients die after a chronic illness of extreme emaciation. In others, concomitant with partial or complete recovery of the marrow most of the striking manifestations classed as anæmia disappear, but they nevertheless succumb to the complications such as lung abscess, tuberculosis, etc.

A typical case: A 31-year old man admitted to the hospital on 5th September, 1945, complaining of epilation, gingival pain and high fever. At the

time of the bombing he was in the military barracks approximately one km. from the centre. At the time he sustained a large wound of the occipital region and lacerations of the upper arm and dorsum of the left foot. On the 25th August the scalp hair began to fall out and he began to complain of gingival pain. At the time of admission his temperature was 39·5 degrees Centigrade, pulse was 102. He was pale and undernourished and appeared moderately ill. There was a striking degree of gingival hæmorrhage and ulcers were present on the lips. It was impossible for him to eat on account of pain. Epilation was complete but no petechiæ were seen on the skin. On 15th September his fever increased and his coughing was so severe that he was unable to sleep. However, his external wounds began to heal. On 14th November there was hæmoptysis of approximately 100 cc. On 15th November, he was in an agonal state and died. His total stay in the hospital was 72 days. On the 19th of September his red blood count was 2·2 millions, Hæmoglobin 36, and white blood 3,200. On 8th November his red count had descended to 1·7 millions but his white blood count had increased to 4,300.

VI

PATHOLOGIC ANATOMY OF RADIATION EFFECTS OF ATOMIC BOMB EXPLOSION

Before considering the radiation effects on the systems of the body, we might consider the relationship of lesions and time of death. In those patients dying during the first two weeks there is histologic evidence of radiation effects in the bone marrow, gonads, gastro-intestinal tract and skin not manifested clinically. In the group dying during the third to sixth weeks, bone marrow changes predominate, and neutropenic ulcerations and hæmorrhagic symptoms are spectacular. General nutrition declines. Gross changes are at about the peak. Those dying in the third and fourth months show beginnings of recovery in bone marrow and hair regeneration but persistence of testicular and connective tissue changes. There is an increased number of emaciated patients. The lack of nutrition is not based entirely on shortage of food. Intestinal lesions and other factors play a big part.

It must be emphasized that much of the Japanese material needs further investigation. The primary analysis has opened the way for future detailed studies.

SKIN: The quickly visible changes in Japanese affected by an atomic bomb were the pigmented areas that appeared in the first few weeks and persisted. These had so sharply demarcated outlines that they were considered as flash burns; whether very soft non-penetrating gamma rays played a role, is not known. Development of what we have recognized as ionizing ray skin burn were not seen. There were a few early cases of bullous œdema that may have been from gamma rays.

Epilation appeared mainly on the scalp and occasionally more on one side than the other; axillary 16 per cent., pubic 12 per cent., eyebrows 8 per cent.

Microscopically the hair follicles show distinct changes both in the epidermic and dermic coats. Early specimens were not obtained but in the fourth week the internal root sheaths cannot be identified, the external sheath (continuous with the malpighian layer of the epiderm) being continuous with the hair shaft. Vascularity of the papillæ is reduced and the adjacent epithelium is atrophic. Pigment is irregularly clumped. Then the dermic coat shows thickening

both of the inner hyaline membrane and the cellular fibrous layer. The bottom of the follicle apparently undergoes a continuous shrinking in pushing the base of the hair toward the surface until regeneration begins with new cells over the papillae in a manner similar to ordinary hair replacement activity. There is also atrophy of the *sebaceous glands,* but this is also present when old hairs are replaced in the normal individual.

Some of the *sweat* glands are small, their cells occasionally vacuolated and pyknotic, and the basal membranes thickened.

Evidence of radiation effects on the skin is not definite. Third degree flash burns could be expected to have also some radiation effect, but interpretation is difficult. In a patient dying on the 5th day there is necrosis of a vessel wall and thrombosis. At the edge of a burn area there is hyperpigmentation in basal cells and chromatophores. Some thinning of epidermis, hyperkeratosis, ironing out of papillæ, and hyperpigmentation of basal cells are found in the scalp (the most usual specimen).

Vascular and collagen changes are minimal.

BRAIN: Only secondary hæmorrhagic or necrotic changes are found.

PITUITARY: Large basophilic cells with much cytoplosmic vacuolation appeared in 25 per cent. of the males dying during the third to sixth weeks. Because cells of this type are found in mammals after castration, they are known as "castration cells". In the second and third months large basophiles are found, only a few being vacuolated.

THYROID AND PARATHYROID: Not remarkable.

ADRENAL: During the first two weeks there seems to be a loss of lipoid in the cortex, but during the next months the cortex progressively loses the orange-yellow colour and is distinctly thin. Microscopically most cells are granular rather than foamy and the atrophy is most marked in the outer zona glomerulosa (contrary to the expected). When foam cells are present they are usually in the inner layer. The medulla is normal.

PANCREAS: No changes were found except for some mitoses in islet cells.

HEART: Epicardial petechiæ are found within the first two weeks and there is microscopic evidence of some perivascular and rare muscle œdema in the myocardium. These changes continue to be present during the second month when myocardial hæmorrhages are also seen After the second month no distinct irradiation changes are found.

LUNGS: Only the slight œdema that appears in the first two weeks might be a primary radiation effect. Hæmorrhagic and necrotizing pneumonia are common after the first weeks, as secondary lesions.

LIVER: Dr. Liebow of the Joint Commission, and Dr. Ono, Professor of Pathology at Fukuoka, were impressed with large nuclei of liver cells around the central veins and with congestive œdema in and around the walls of the central vein; however, the presence of any irradiation effects is a moot point.

KIDNEY AND URETER: Except for hæmorrhagic manifestations there are no primary lesions.

BLADDER: During the hæmorrhagic stage of the radiation disease, mucosal hæmorrhages may result in necrotizing ulceration without evidence of leucocytic infiltration.

PROSTATE AND SEMINAL VESICLES: Not remarkable except for a rare neutropenic necrosis and the presence of a few morphologically normal spermatozoa.

TESTES: The testes show intense changes in almost every cadaver. As early as the fourth day when the parenchyma has a normal appearance grossly, the histologic sections present remarkable injury to the germinal epithelium, numerous cells of which are necrotic and free in the tubules and even carried into the rete testis. The number of mitoses is small. Sertoli cells begin to increase in number. Mature spermatozoa are found even in later specimens with no spermatogenesis. Apparently uninjured spermatozoa appear in the seminal vesicles. During the second month gross examination reveals little. A few necrotic germ cells remain but most have disappeared and phagocytic or infiltrating inflammatory cell activity is absent. A few bizarre cells still approximating the basal membrane appear to be spermatogonia. Sertoli cells are more numerous. The tubules now begin to shrink: at this time also the interstitial cells of Leydig are so prominent that some interpreters think they are hyperplastic. Some of the small interstitial vessels show the most marked vascular change of any part of the body; beneath the distinct thin endothelium is an eccentrically located mass of eosinophilic homogeneous refractile material that may almost occlude the lumen. This change is often best seen near the tunica albuginea and is present also in the cases of the third and fourth months. Now also the interstitial tissue is less but still prominent. The basement membranes are quite thick, wavy and acellular. The tubules, now more atrophic, are often hyalinized. Elsewhere Sertoli cells have replaced the germ cells, which are rare. During the third and fourth months it must be remembered that the state of nourishment is poor and that specimens from the Dachau German prison camp have been described as showing similar testicular changes.

OVARIES: Changes here are much less striking. Gross changes, except as part of the hæmorrhagic phenomena, are absent, even to the presence of a well developed corpus luteum of pregnancy seen about the end of the first month after irradiation. Histologically, primary ova are usually present and only occasional specimens have a few atretic primary follicles. The absence of developing follicles is a usual condition. There are no corpora lutea and the "resting phase" of the endometrium reflects this. Amenorrhœa was distinctly increased in Nagasaki and a significant number of abnormal births and increased death rate of the mothers in relation to distance from the explosion was found there.

GASTRO-INTESTINAL: This tract was among the first to show gross lesions. Even before hæmorrhagic manifestations the cæcum or colon, particularly, may present a widespread change marked by swelling, greenish and yellowish-grey coloration and induration of the mucosa, sometimes with a diphtheritic membraneous effect, and with much submucosal œdema. Later mucosal hæmorrhage may institute another cycle of similar change in the stomach or intestine. This change may begin with ulceration of the mucosa at the site of the hæmorrhage and progress to an ulcerative or pseudo-membranous process. Again in the third and fourth months an enteritis most usually in the large intestine but sometimes affecting also the small intestine or occasionally the stomach may be the most prominent lesion at autopsy. In the small intestines only the tips of the folds may be first involved.

These first look as if they have been dipped in boiling water and then become greenish or yellowish-grey. Fewer specimens of small intestine have a diffuse mucosal process.

The large intestine in this late stage usually has a more widespread process that may extend from the ileocecal valve to the rectum. The thickened wall is a feature. A diphtheritic membrane and ulceration are sometimes present so that the morphology is quite similar to that of bacillary dysentery. It seems that much of the process here is not only change from irradiation of the sensitive intestine but to the lowered local ability to cope with omnipresent intestinal micro-organisms and, probably more important, to the lowered antibiotic capabilities of the blood.

Microscopically, the epithelium early contains extremely bizarre cells with giant hyperchromatic nuclei and multipolar mitoses. The swelling is seen to be from œdema and the peculiar colouration from the absence of infiltrating leucocytes. Late cases show areas of mucosal ulceration with much fibrin, few leucocytes; and in the remarkably œdematous submucosa quite a few histiocytes, a few lymphocytes and occasional eosinophils. Plasma cells of the lamina propria remain numerous.

SPLEEN: The lymphoid elements here react to radiation as in the nodes. Early the spleens are usually small, but occasional ones show the very early swelling reaction. On section they are dark red, little scrapes off on the knife, the follicles are indistinctly seen and the trabeculæ are somewhat prominent. Besides the near absence of lymphocytes, large mononuclears are increased and there is erythrophagocytosis and hemosiderin deposits. During the second month the spleen is small and follicles are absent. There seems to be a syncitial reticulum around the follicles in which the slight lymphocytic content of the organ is seen. Atypical large mononuclears are found in about 25 per cent. Through the fourth month there is still some atrophy. Occasional germinal centres appear and lymphocytic content shows some evidence of recovery.

LYMPH NODES: The high sensitivity of lymphoid tissue to ionizing radiation results in tremendous atrophy seen as early as the third day. Lymphocytes almost disappear leaving a lacy framework that is quite spectacular histologically. A similar picture is found in the tonsils and other lymphoid tissue. Changes in the germinal centres may be necrobiosis, but a departure from normal is not marked except when the germinal centres disappear as they did in three-fourths of the first-two weeks' deaths. The early gross appearance of human nodes is not known but bombed animals showed some enlargement, softening and a paler colour. By the second week large atypical mononuclear cells, considered by one observer as lymphoblasts, appear; these cells logically could be pathologic forms whose sensitive nuclear chromatin was deformed by the radiation. About the fifth week, the nodes are usually small and almost devoid of lymphocytes and germinal centres. Bizarre large cells are more numerous. Plasma cells, eosinophiles and mast-cells along with increased numbers of reticulum cells are present. Lymphocytes are more numerous in the fourth month but still reduced.

BONE MARROW: The cellular picture of irradiated bone marrow is tremendously changed during the first week after the bomb explosion. There is almost total disappearance of blood-forming elements except small islands of erythropoiesis, which are less sensitive. By the end of the week reticulum begins to proliferate and differentiates first into lymphocytes and plasma cells rather than myeloid cells. This type of differentiation is predominant until the fourth week when myeloid differentiation is seen. Most marrows of those dying before six weeks are hypoplastic but a few show

hyperplasia with maturation arrest. Most of the fatal cases of the third and fourth months show hyperplasia, which in the femur was grossly evident as pink marrow extending from a third to half of the shaft; in these the maturation defect decreases and more neutrophiles are found in the peripheral blood and in infected tissues. A few of these older cases, however, show aplasia with pink gelatinous femur marrow. Some grossly appearing hyperplastic marrows are really hypoplastic, the pink colour coming from dilated blood vessels. Whatever the marrow picture there is usually a profound leukopenia at some time in those patients dying in the first six weeks. Later leukopenia does not persist and even those who die develop leucocytosis except for the few who have aplastic marrows.

Secondary Effects of Radiation of Reticulo-Endothelial System.

HÆMORRHAGIC LESIONS AND LEUKOPENIC NECROSIS affect the irradiated body about the end of the first month, mainly. The pharynx and its connections, the gastro-intestinal tract, the respiratory organs and the skin manifest both changes; in addition, particularly the urinary tract, mesothelial linings, and muscles, but including all body soft tissues, show petechiæ, purpuric patches or large ecchymoses. These changes are outstanding clinically. Severity depends on the location of the larger hæmorrhagic lesions. Hæmorrhages in the linings of the pharyngeal regions, of the bowel or of the urinary tract give signs externally. Large submucosal hæmorrhages as well as petechiæ appear in the kidney pelves and in the bladder and sometimes in the ureters. Hæmorrhages breaking through epithelium of bacteria-laden surfaces often initiate the neutropenic necrotizing lesions which in the pharynx are similar to the well known acute agranulocytosis. Ulcers sometimes extend on to the tongue, the gums, buccal membranes, lips, and even the skin to give a picture of noma. Such ulceration also begins independent of hæmorrhage. It is probable that bacteria ordinarily non-pathogenic may cause serious consequences on the loss of sufficient reticulo-endothelial reserves. Ulcerative lesions throughout the stomach and intestinal tract are on a similar basis, as indeed, it appears that many of the diffuse mucosal changes may be. The necrotizing pneumonia appears to be a part of this picture. There is little leucocytic reaction in these lesions, which overwhelm the patient and lead to death. A case history example is as follows:—

This 29-year-old man was at distance of 0·7 km. He was outdoors a few paces from a concrete building. He was struck by a falling roof which inflicted slight injuries of the head and neck. There was nausea on 6th August and on the same day he vomited between 20 and 30 times. Malaise began on 6th August and lasted until the 10th, accompanied by anorexia. He again experienced malaise beginning with 21st August until time of death. Anorexia appeared 4 days after the second onset of malaise. There was epilation and gingivitis on 21st August, which persisted. The gingivæ began to bleed on 30th August. On the 25th there began purpuric manifestaations and there was evidence of tonsilitis the same day. Both of these symptoms lasted until death on 1st September. There was a high degree of fever between 24th August and time of death and there was cough and sputum beginning on the 25th, with a hæmoptysis on 30th August.

LABORATORY DATA:	RBC	Hgb	WBC
24th August	3·95	78	370
26th August	5·64	80	450
29th August	4·19	65	200
30th August	...	...	220

The urine examined on 29th August, was positive for albumin and negative for sugar. No statement is made concerning sediment.

Sections of marrow in this patient, derived apparently from a cavity of a long bone, are hyperplastic, showing vascular adipose tissue crowded by very large numbers of young myelocytes. Mature polymorphonuclear leukocytes and even stab cells are rare. There is an occasional megakaryocyte. Occasional cells are found in mitosis. A few small cells of shrunken nuclei thought to be normoblasts also are found. Other important lesions at necropsy were petechiæ of skin, epilation of scalp, focal necrosis of pharynx, tongue, tonsils and larynx, necrotizing gingivitis, an abscess in the region of the right mandibular joint, necrotizing and hæmorrhagic aplastic pneumonia, minute hæmorrhages of gastro-intestinal tract, trachea and renal pelvis.

VII

THERAPY OF RADIATION DISEASES

The therapy of acute radiation is initially the therapy of a severe hæmorrhagic diathesis which may or may not be associated with severe infections as a result of the marked granulocytopenia. Hæmorrhage tends to precede the infectious processes. At the present time massive, daily transfusions offer the best chance of help in combatting the hæmorrhage. The antiheparin agents such as toluidine blue and protamine show considerable experimental promise. Endeavours toward combatting the granulopenia and infections secondary to it are the prophylactic use of penicillin in large daily doses, the preparation and administration of leucocyte cream according to technique of Strumia, and perhaps the use of streptomycin. Yellow bone marrow extract, pento-nucleotide, sodium nucleonate, liver extract, and adenine sulphate are of no proven value. Folic acid may be of some value and should be given a trial orally. Insomuch as hypodermic injections are a common portal of entry for pathogens in acute radiation disease parenteral injections should be kept to a minimum. The following outline may serve as a guide:—

1. Scrupulous sterile technique.
2. Careful nursing care of skin, teeth, mouth, and excretory organs.
3. Penicillin prophylactically perhaps 2½ million units daily.
4. Transfusions—500 cc./day.
5. Leucocytic cream—daily.
6. Folic Acid—25 mgm./day orally.
7. Streptomycin if E. coli bacteremia occurs.
8. Follow the course by daily blood counts, blood cultures and urine cultures. Samples of blood can be withdrawn at the time transfusions are given so as to minimize the number of cutaneous punctures.

THERAPY OF PLUTONIUM POISONING

Numerous methods have been proposed to accelerate the elimination of plutonium, radium, etc. None has been very promising. Recent work by Schubert indicates that Zirconium is very effective in displacing plutonium from the body in animals. The preliminary report on this work is in: *Science*—Vol. 105:389 of 11th April, 1947.

Treatment of the anæmia, the granulocytopenia, etc., would follow the lines listed above.

VIII

PUBLIC HEALTH ASPECTS OF THE ATOMIC BOMB

1. Assessment of health hazard to be based on physical findings (type and degree of radioactivity):—

(*a*) Contamination of area with alpha emitters will constitute a most serious hazard if such substances gain access to the interior of the body. None from external radiation.
(*b*) Contamination with beta emitters constitutes both external and internal radiation hazard (more serious per unit if internal).
(*c*) Contamination with gamma emitters constitutes both external and internal radiation hazard (from a practical standpoint more serious external).
(*d*) Contamination will almost certainly not be limited to one of the above types of radiation.

2. Advice as to the eating of food within the contaminated area.

(*a*) It must be assumed that all food found in the area is dangerous:—

1. Induced activity;
2. Deposited activity;
3. Canned or otherwise protected foods to be eaten only after careful inspection by expert.

Rule: No food is to be eaten in a contaminated area. This rule must be tempered, interpreted and administered with tact and discretion.

3. Advice as to the drinking of water in the contaminated area.

(*a*) May be a part of general area contamination or may have become contaminated upstream.
(*b*) Take potable water in with you if possible.
   1. Take precautions to prevent contamination.
(*c*) Methods of decontamination.
   1. Physical.
      (*a*) Boiling—useless or harmful.
      (*b*) Storage—not practical.
      (*c*) Filtration—discuss.
   2. Chemical.
      (*a*) Useless.
   3. Physico-chemical.
      (*a*) Precipitaton and filtration—discuss.

4. Prevention of dissemination.

(*a*) Decontamination centre for area evacuation.

1. Clothing change and bathing facilities.
2. Laundry (decontamination) facilities.
3. Monitoring facilities.
4. Eating and surgical dressing only on "clean" side.

(*b*) On entering contaminated zone.

1. Remove all clothing (or outer clothing).
2. Leave all smokes and eats behind.
3. Go to " dirty " side and put on work clothes (overalls, hat, gloves and boots).

(*c*) On leaving contaminated zone.

1. Remove hat and gloves.
2. Wash face, neck and hands thoroughly five times with soap and water.
3. Remove remaining clothing.
4. Soap and thoroughly wash entire body five times.
5. Go to monitoring room (between shower and clean side).
6. With permission of monitor go to clean side and put on original clothing.

IX

A SELECTED READING LIST OF ARTICLES ON ATOMIC ENERGY

1. " Action of Radiation on Living Cells " (Cambridge—1947) D. E. Lea.
2. " Applied Nuclear Physics " (Wiley—1946) Pollard and Davidson.
3. " Artificial Radio-active Tracers " Science *105*, 349 (1947) G. T. Seaborg.
4. " Chemical and Engineering News " (May 25th, 1946). A Series of Articles by such authorities as J. P. Oppenheimer, et al.
5. " Explaining the Atom " (Viking—1947) S. Hecht.
6. " General Rules and Procedures Concerning Activity Hazards ". Declassified A.E.C. Report MDDC-247.
7. " Radio-activity and Nuclear Physics " (Edwards Brothers—1946) J. M. Cork.
8. " Seminar Notes in Nuclear Science and Engineering ", Mass. Institute of Technology, Department of Physics.
9. " The Atomic Bomb " Atomic Scientists of Chicago (1946).
10. " The International Control of Atomic Energy " U.S. State Dept. U.S. Representative Report No. 5 (1946).
11. " The Medical Uses of Atomic Energy " Atlantic Monthly, R. D. Evans (1946).
12. " The Particles of Modern Physics " (Blakeston 1943) J. D. Stranathan.
13. " The Physiological Effects of Neutron Rays " American Review of Physiology, Vol. IV, pp. 25-48 (1942) P. C. Aebersold and J. H. Lawrence.
14. " Tolerance Concentrations of Radio-active Substances " Declassified A.E.C. Report MDDC-240, K. Z. Morgan.

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(b) On entering contaminated zone:

1. Remove all clothing for later cleaning.
2. Leave all smokes and eats behind.
3. Go to "dirty" side and put on work clothes, coveralls, gloves and boots.

(c) On leaving contaminated zone:

1. Remove [illegible] gloves.
2. Wash face, neck and hands thoroughly five times with soap and water.
3. Remove remaining clothing.
4. Soap and thoroughly wash entire body five times.
5. Go to monitoring room (between shower and clean side).
6. With permission of monitor go to clean side and put on ordinary clothing.

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2. "Applied Nuclear Physics" (Wiley, 1942) Pollard and Davidson.
3. "Artificial Radioactive Tracers," Science [illegible]
4. "Chemical and [illegible]" [illegible]
5. "Explaining the Atom" (Viking, 1947) S. Hecht.
6. "[illegible]" [illegible] A.E.C. Report MDDC [illegible]
7. "[illegible] and Nuclear Physics" [illegible]
8. [illegible]
9. [illegible]
10. "The International Control of Atomic Energy" [illegible]
11. [illegible]
12. "The Particles of Modern Physics" (Blakiston, 1948) J. D. Stranathan.
13. "The Physiological Effects of [illegible]" [illegible]
14. "Tolerance Concentrations of Radioactive Substances" Declassified A.E.C. Report MDDC [illegible]